RULES FOR CLASSIFICATION

Ships

Edition October 2015
Amended January 2016

Part 2 Materials and welding
Chapter 3 Non-metallic materials
FOREWORD

DNV GL rules for classification contain procedural and technical requirements related to obtaining and retaining a class certificate. The rules represent all requirements adopted by the Society as basis for classification.

© DNV GL AS October 2015

Any comments may be sent by e-mail to rules@dnvgl.com

If any person suffers loss or damage which is proved to have been caused by any negligent act or omission of DNV GL, then DNV GL shall pay compensation to such person for his proved direct loss or damage. However, the compensation shall not exceed an amount equal to ten times the fee charged for the service in question, provided that the maximum compensation shall never exceed USD 2 million.

In this provision "DNV GL" shall mean DNV GL AS, its direct and indirect owners as well as all its affiliates, subsidiaries, directors, officers, employees, agents and any other acting on behalf of DNV GL.
CHANGES – CURRENT

This is a new document.
The rules enter into force 1 January 2016.

Amendments January 2016

- General
  - Only editorial corrections have been made.

Editorial corrections

In addition to the above stated changes, editorial corrections may have been made.
## CONTENTS

Changes – current.................................................................................................................. 3

### Section 1 General......................................................................................................... 7

1 General............................................................................................................................. 7

1.1 Scope......................................................................................................................... 7

1.2 Application.................................................................................................................. 7

1.3 Relation to other Society documents....................................................................... 7

2 References....................................................................................................................... 7

2.1 References.................................................................................................................. 7

2.2 Abbreviations, symbols and terminology.................................................................. 7

### Section 2 Composite materials................................................................................... 12

1 General............................................................................................................................. 12

1.1 Scope......................................................................................................................... 12

1.2 Application.................................................................................................................. 12

1.3 Documentation and certification requirements.......................................................... 12

2 Glass fibre reinforcements............................................................................................. 13

2.1 Chemical composition............................................................................................... 13

2.2 Properties................................................................................................................... 13

3 Carbon fibre reinforcements.......................................................................................... 14

3.1 General....................................................................................................................... 14

3.2 Properties................................................................................................................... 14

4 Aramid fibre reinforcements.......................................................................................... 16

4.1 General....................................................................................................................... 16

4.2 Tensile and compressive strength............................................................................. 16

4.3 Laminate requirements.............................................................................................. 17

5 Polyester and vinyl ester resins.................................................................................... 18

5.1 Resin properties.......................................................................................................... 18

5.2 Fire retardant resin properties................................................................................... 20

5.3 Gelcoat and topcoat properties................................................................................ 21

5.4 Fire retardant gelcoat and topcoat properties.......................................................... 21

6 Epoxy Resin Systems.................................................................................................... 21
### Part 2 Chapter 3

### Contents

- **6.1 General** ................................................................. 21
- **6.2 Quality control** ......................................................... 21
- **6.3 Requirements for curing** ............................................ 22
- **6.4 Fire retardant qualities** .............................................. 23

**7 Prepreg materials** .......................................................... 23

- **7.1 General requirements** ............................................... 23
- **7.2 Properties** ............................................................... 24

**8 Sandwich core materials** .................................................. 25

- **8.1 General requirements** ............................................... 25
- **8.2 Requirements to all core materials (closed cell foams)** ....... 25
- **8.3 Core materials in slamming exposed areas** .................... 28
- **8.4 Core materials in fatigue exposed areas** ......................... 28
- **8.5 Requirements to cross-cut balsa wood** .......................... 29

**9 Sandwich adhesives** ........................................................ 30

- **9.1 Properties** ............................................................... 30

**10 Adhesives** ................................................................. 31

- **10.1 General** ............................................................... 31
- **10.2 Requirements to rigid adhesives** ................................. 32
- **10.3 Requirements to flexible adhesives** ............................. 33
- **10.4 Requirements to sealants** .......................................... 35

### Section 3 Manufacture of products made of FRP

**1 General** ............................................................................. 37

- **1.1 Scope** ........................................................................... 37

**2 Handling of raw materials** ............................................... 37

- **2.1 Storage** ....................................................................... 37
- **2.2 Manufacturing premises and conditions** ......................... 38

**3 Production procedures and workmanship** ............................ 39

- **3.1 General** ....................................................................... 39
- **3.2 Sandwich lay-up** .......................................................... 39
- **3.3 Manual lamination** ....................................................... 40
- **3.4 Vacuum assisted resin transfer moulding (VARTM) and vacuum-bagging** ................................................. 41
- **3.5 Spray moulding** ............................................................ 41
- **3.6 Curing** ......................................................................... 41

**4 Bonding** ............................................................................ 42

- **4.1 Secondary bonding** ....................................................... 42
- **4.2 Bonding with rigid adhesives** ........................................ 42
- **4.3 Bonding with flexible adhesives** ..................................... 43
5 Quality assurance and quality control.................................................. 46
  5.1 Quality assurance................................................................. 46
  5.2 Quality Control....................................................................... 46
  5.3 Production testing................................................................. 47

Section 4 Wooden materials........................................................................ 49
  1 General....................................................................................... 49
    1.1 Classification according to the field of application.................. 49
    1.2 Quality of timber................................................................. 49
    1.3 Drying.................................................................................... 49
  2 Types of wood and classifications.................................................... 49
    2.1 Solid wood........................................................................... 49
    2.2 Plywood............................................................................... 51
  3 Boatbuilding plywood....................................................................... 51
    3.1 General............................................................................... 51
    3.2 Structure............................................................................. 52
    3.3 Veneer joints........................................................................ 53
    3.4 Strength groups.................................................................... 53
    3.5 Plywood grades.................................................................... 53
    3.6 Defects.................................................................................. 53
    3.7 Repairs.................................................................................. 54
    3.8 Surface treatment................................................................. 54
    3.9 Panel dimension.................................................................... 54
    3.10 Testing................................................................................ 54
    3.11 Marking and stamping......................................................... 58
    3.12 Certificates......................................................................... 59
    3.13 Storage of the plywood panels............................................. 59
  4 Joining of wood materials............................................................... 60
    4.1 Laminated and multilayered components................................. 60
    4.2 Scarf jointing.......................................................................... 60
  5 Wood Protection............................................................................... 61
    5.1 General............................................................................... 61

Section 5 Acrylic plastic............................................................................ 62
  1 General....................................................................................... 62
    1.1 Scope................................................................................... 62
    1.2 Certification........................................................................... 62
    1.3 Acrylic plastic materials....................................................... 62
    1.4 Manufacture of windows....................................................... 62
SECTION 1 GENERAL

1 General

1.1 Scope

1.1.1 The chapter specifies the requirements for non-metallic materials used for construction of vessels and their equipment with respect to:
— manufacturer and manufacture
— composition and technology
— testing
— inspection and survey
— identification and certification.

1.1.2 Upon agreement, the scope may be extended to non-metallic materials used for other applications.

1.2 Application

1.2.1 The rules in this section apply to the following materials:
— composite materials and adhesives
— fibre reinforced plastics (FRP)
— wooden materials
— acrylic plastics.

1.3 Relation to other Society documents

1.3.1 The general requirements for manufacture and fabrication of materials and components are given in Ch.1. Additional requirements may also be provided in each section of this chapter as well as in other parts of the rules. In case of conflicting requirements, the specific or additional requirements in other parts of the rules are prevailing.

2 References

2.1 References

2.1.1 Relevant standards are introduced throughout these rules. Unless otherwise agreed, the latest versions of the referred standards valid at the date of release for the current rules are applicable.

2.2 Abbreviations, symbols and terminology

2.2.1 General abbreviations and symbols are given in Ch.1 Sec.4.
2.2.2 General terminology is given in Pt.1 Ch.1 Sec.1 [1.2]. Special terminology is given in Table 1.

Table 1 Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Certificate of Analysis (CoA)</td>
<td>A document issued by Quality Assurance that confirms that a regulated product meets its product specification. A CoA commonly contains the actual results obtained from testing performed as part of quality control of an individual batch of a product</td>
</tr>
<tr>
<td>Complex of fibres</td>
<td>Unidirectional layers of fibres randomly arranged one above the other, and either glued or tacked to one another or to mats by thin fibre strands. Different layers may be of different materials and/or thread counts</td>
</tr>
<tr>
<td>Fabric</td>
<td>Fibre strands woven together, the conventional weave types for textiles such as plain, twill, satin or linen being employed. Warp and weft may differ as regards material and/or thread count. Fabrics may also be produced by stitching rather than weaving</td>
</tr>
<tr>
<td>Fibre-reinforced plastics (FRP)</td>
<td>Heterogeneous materials, consisting of a thermosetting resin as the matrix and an embedded reinforcing material</td>
</tr>
<tr>
<td>Laminate</td>
<td>A cured moulded part which is manufactured by placing layers of reinforcing material on top of each other together with the thermosetting resin</td>
</tr>
<tr>
<td>Mat</td>
<td>Random layering of continuous filaments or strands of fibres at least 50 mm long, bonded together by means of a binder</td>
</tr>
<tr>
<td>Prepreg</td>
<td>Reinforcing material which is pre-impregnated with a thermosetting resin which can be processed without any further addition of resin or hardener</td>
</tr>
<tr>
<td>Reinforcing materials</td>
<td>Materials generally in the form of fibre products which are embedded in a matrix in order to achieve certain properties. The fibres are processed in the form of semi-finished textile products (mats, rovings, fabrics, non-wovens). For special requirements, mixtures of different fibre materials are also used (hybrids)</td>
</tr>
<tr>
<td>Roving</td>
<td>A multiplicity of filaments or yarns gathered together into an approximately parallel arrangement without twist</td>
</tr>
<tr>
<td>Sandwich laminate</td>
<td>Two laminate layers connected together by means of an intermediate core of a lighter material</td>
</tr>
<tr>
<td>Thermosetting resin</td>
<td>Two-component mixture consisting of resin and hardener as well as possible additives</td>
</tr>
</tbody>
</table>

2.2.3 General abbreviations and symbols are given in Ch.1 Sec.4. Additional abbreviations for this chapter are given in Table 2.

Table 2 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full text</th>
</tr>
</thead>
<tbody>
<tr>
<td>mean</td>
<td>arithmetic mean of type test results</td>
</tr>
<tr>
<td>sdev</td>
<td>standard deviation of type test results</td>
</tr>
<tr>
<td>m ± 2 sdev</td>
<td>mean ± 2 sdev of type test results</td>
</tr>
<tr>
<td>msv</td>
<td>manufacturer’s specified value</td>
</tr>
<tr>
<td>msmv</td>
<td>manufacturer’s specified minimum value</td>
</tr>
<tr>
<td>num</td>
<td>number of specimens</td>
</tr>
</tbody>
</table>
3 Documentation and certification requirements

3.1 Certification requirements

3.1.1 General certification requirements are given in Ch.1 Sec.1 [3.1]. Certification requirements for non-metallic materials relevant for application are given in the relevant design rules. Specific certification requirements are given in Table 3. Where applicable, additional specific certification requirements are given within each of the following sections.

Table 3 Certification requirements

<table>
<thead>
<tr>
<th>Object</th>
<th>Certificate type</th>
<th>Issued by</th>
<th>Additional description</th>
<th>Certification standard*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials</td>
<td>TA</td>
<td>Society</td>
<td>Materials to be delivered with W certificate</td>
<td></td>
</tr>
<tr>
<td>Personnel</td>
<td>Training course certificate</td>
<td>Independent organization</td>
<td>The pre-treatment of the joining surfaces and the bonding of structural components shall only be performed by persons with adequate skills and professional knowledge. This professional knowledge shall be documented by means of certificates from the corresponding training courses</td>
<td>* )</td>
</tr>
<tr>
<td>Workshops</td>
<td>Society certificate</td>
<td>Society</td>
<td>Manufacture of FRP-components shall only be performed by workshops which are approved by the Society</td>
<td>* )</td>
</tr>
</tbody>
</table>

* unless otherwise specified the certification standard is the Society's rules

1) the approval procedures for the materials covered in this section are specified in the respective type approval programmes

Non-metallic materials

t thickness of tested laminate

N number of cycles

σ_{static} manufacturer’s specified minimum value, tensile or compressive, whichever is lesser

x other main fiber direction
3.2 Documentation requirements

3.2.1 General documentation requirements are given in Ch.1 Sec.1 [3.2]. Additional manufacturer specific documentation requirements are given in Table 4. Further specific documentation requirements are given in each section as relevant.

Table 4 Qualification documentation for manufacturer

<table>
<thead>
<tr>
<th>Item</th>
<th>Documentation type</th>
<th>Additional description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Z251 - Test procedure</td>
<td>For testing and retesting, listing the relevant reference standards</td>
</tr>
<tr>
<td></td>
<td>Z260 - Report</td>
<td>Where a deviation from approved process occurs and this could produce material of inferior quality</td>
</tr>
<tr>
<td>Materials</td>
<td>Z270 - Records</td>
<td>From inspections:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— the manufacturer shall maintain records of inspections and measurements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— the records shall be presented to the surveyor on request</td>
</tr>
<tr>
<td>Manufacturers</td>
<td>TA certificates</td>
<td>Manufacturers delivering materials with W certificate shall have type approval from the Society for the material quality</td>
</tr>
</tbody>
</table>

3.3 Survey, inspection and testing requirements

3.3.1 General survey, inspection and testing requirements are given in Table 5, and further detailed in Sec.2 to Sec.5.

Table 5 Survey and testing requirements

<table>
<thead>
<tr>
<th>Survey, inspection and testing item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type approval</td>
<td>— the manufacturer shall carry out a test program and submit the results, as described in the relevant type approval programme</td>
</tr>
<tr>
<td></td>
<td>— the surveyor shall be given the opportunity to witness and survey all relevant processes and tests</td>
</tr>
</tbody>
</table>
| Manufacturing plant, manufacturing process, materials and testing | — the surveyor shall be given the opportunity to survey and check at any time all plants and equipment used in the manufacture and testing  
— the manufacturer shall assist the surveyor to enable him to verify that approved processes are adhered to and to witness the selection and testing as required by the rules  
— spray moulding of structural members shall be carried out only by specially approved operators |
|---|---|
| Inspection | — all materials shall be checked by the manufacturer for compliance with the specification. The material shall be in the prescribed delivery condition  
— materials that do not meet the required specification shall be clearly marked accordingly  
— the materials shall, when called for, be presented to the surveyor in the condition described above |
| Chemical composition | — where relevant, the chemical composition of samples shall be determined by the manufacturer in an adequately equipped and competently staffed laboratory and shall comply with the appropriate specification |
| Selection and marking of test material | — all the test material shall be selected and marked by the surveyor, unless otherwise agreed |
| Testing of materials | — all specified tests shall be carried out by an accredited or the Society recognized testing laboratory  
— according to prior agreement with the Society the required tests can be carried out in the in-house testing laboratory in the presence of a surveyor  
— the surveyor may require further tests when deemed necessary  
— all tests shall be carried out by competent personnel on machines of accepted type |
| Retesting | — requirements for retesting shall be agreed with the surveyor |
SECTION 2 COMPOSITE MATERIALS

1 General

1.1 Scope

1.1.1 This section gives the requirements to approval for composite raw materials.

1.2 Application

1.2.1 The requirements in this section apply to raw materials for fibre-reinforced plastic (FRP) structures classed or intended for classification with the Society.

1.2.2 Fibre reinforcements other than glass fibre, carbon fibre and aramid fibre, resins other than polyester, vinyl ester and epoxy, and coatings other than gelcoat and topcoat, may be accepted based upon testing and approval in each individual case.

1.3 Documentation and certification requirements

1.3.1 General certification requirements are given in Sec.1 [3.1]. Specific certification requirements are given in Table 1.

Table 1 Certification requirements

<table>
<thead>
<tr>
<th>Object</th>
<th>Certificate type</th>
<th>Issued by</th>
<th>Additional description</th>
<th>Certification standard*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glass fibre reinforcements</td>
<td>MC</td>
<td>Manufacturer</td>
<td>Rovings and fabrics</td>
<td>2)</td>
</tr>
<tr>
<td>Carbon fibre reinforcements</td>
<td>MC</td>
<td>Manufacturer</td>
<td>Yarns and fabrics</td>
<td>2)</td>
</tr>
<tr>
<td>Aramid fibre reinforcements</td>
<td>MC</td>
<td>Manufacturer</td>
<td>Fibres and fabrics</td>
<td>2)</td>
</tr>
<tr>
<td>Prepreg materials</td>
<td>MC</td>
<td>Manufacturer</td>
<td></td>
<td>2)</td>
</tr>
<tr>
<td>Polyester resins</td>
<td>MC</td>
<td>Manufacturer</td>
<td></td>
<td>2)</td>
</tr>
<tr>
<td>Vinyl ester resins</td>
<td>MC</td>
<td>Manufacturer</td>
<td></td>
<td>2)</td>
</tr>
<tr>
<td>Epoxy resins</td>
<td>MC</td>
<td>Manufacturer</td>
<td></td>
<td>2)</td>
</tr>
<tr>
<td>Gelcoats and topcoats</td>
<td>MC</td>
<td>Manufacturer</td>
<td>Including fire retardant gelcoat and topcoat</td>
<td>2)</td>
</tr>
<tr>
<td>Sandwich core materials</td>
<td>MC</td>
<td>Manufacturer</td>
<td>Including balsa wood</td>
<td>2)</td>
</tr>
<tr>
<td>Sandwich adhesives</td>
<td>MC</td>
<td>Manufacturer</td>
<td></td>
<td>2)</td>
</tr>
<tr>
<td>Adhesives</td>
<td>MC</td>
<td>Manufacturer</td>
<td>Including rigid and flexible adhesives, and sealants</td>
<td>2)</td>
</tr>
</tbody>
</table>

*) unless otherwise specified the certification standard is the Society’s rules

1) W certificates from manufacturers holding a valid type approval certificate for the material quality
2) the approval procedures for the materials covered in this section are specified in the respective Society type approval programmes
1.3.2 General documentation requirements are given in Sec.1 [3.2]. Additional manufacturer specific documentation requirements are given in Table 2. Further specific documentation requirements are given in each section as relevant.

Table 2 Qualification documentation for manufacturer

<table>
<thead>
<tr>
<th>Item</th>
<th>Documentation type</th>
<th>Additional description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production testing of products made from FRP</td>
<td>Z261 - Report</td>
<td>The test results shall be in accordance with the values of mechanical strength used in the design and indicate a level of workmanship in line with good industry standard. The test results shall be submitted to and approved by the Society</td>
</tr>
</tbody>
</table>

2 Glass fibre reinforcements

2.1 Chemical composition

2.1.1 The glass shall be of E-glass quality where the sum of Na₂O and K₂O shall be less than 1%. A certificate showing chemical composition shall be presented, or a chemical analysis shall be carried out showing that the requirements to the E-glass quality have been met, i.e. SiO₂ 52-56%, CaO 16-25%, Al₂O₃ 12-16%, B₂O₃ 6-12%, Na₂O + K₂O 0-1% and MgO 0-6%.

2.1.2 Fibres made of other glass qualities, such as E-CR-glass, S-glass or R-glass qualities, may be used subject to special agreement.

2.1.3 Sizing of silane compound or complex chromium compound shall be used. The sizing shall be matched to the thermosetting resin, in order to ensure adequate material properties, also under the influence of media.

2.2 Properties

2.2.1 The glass fibres shall be produced as continuous fibres. They are tested in that product form that shall be used at the production site.

2.2.2 For roving that will be applied by spraying, a demonstration shall be made in the presence of a surveyor which shall show that the roving is suitable for this form of application.

2.2.3 For direct draw rovings, no further proof is needed if the average filament diameter does not exceed 19 µm.

2.2.4 Requirements for glass fibre products are given in Table 3.

Table 3 Glass fibre reinforcements

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>ISO 3344</td>
<td>Maximum 0.2% on delivery</td>
</tr>
<tr>
<td>Loss on ignition</td>
<td>ISO 1887</td>
<td>The manufacturer’s nominal value. Tolerance limits for the various materials are subject to approval in each separate case</td>
</tr>
</tbody>
</table>
3 Carbon fibre reinforcements

3.1 General

3.1.1 The carbon fibre yarn shall be of HT (High Tensile Strength) or HM (High Modulus) quality made of PAN (Polyacrylonitrile) or pitch based precursors with a maximum number of 48k.

3.1.2 Fibres made of other qualities than those specified in [3.1.1] may be used subject to special agreement and provided that their mechanical properties are equivalent or better.

3.2 Properties

3.2.1 Sizings based on epoxy resin shall be used.

3.2.2 Requirements for carbon fibre products are given in Table 4, Table 5, Table 6 and Table 7.

Table 4 Physical requirements for carbon fibre reinforcements

<table>
<thead>
<tr>
<th>Property 1)</th>
<th>Test method 2)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>ISO 3344</td>
<td>msv</td>
</tr>
<tr>
<td>Size content</td>
<td>ISO 10548</td>
<td>msv</td>
</tr>
<tr>
<td>Linear density of the yarn</td>
<td>ISO 1889</td>
<td>Manufacturer's nominal value ± 5%</td>
</tr>
<tr>
<td>Weight per unit area of the fabric</td>
<td>ISO 3374</td>
<td>Manufacturer's nominal value ± 10% - fabrics, weaves, etc.</td>
</tr>
</tbody>
</table>

1) unless otherwise agreed, all parameters shall be tested and documented in W certificate
2) other standards may be agreed upon with the Society prior to testing
Table 5 Tensile testing of carbon fibre yarns

<table>
<thead>
<tr>
<th>Fibre type</th>
<th>Test method 1)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>HT</td>
<td>ISO 10618</td>
<td>Tensile strength MPa 3000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tensile modulus MPa 235000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elongation % 1.4</td>
</tr>
<tr>
<td>HM</td>
<td>ISO 10618</td>
<td>Tensile strength MPa 2000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tensile modulus MPa 350000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Elongation % 0.4</td>
</tr>
</tbody>
</table>

1) other standards may be agreed upon with the Society prior to testing

Table 6 Tensile, compressive and flexural testing of laminates made of fabrics (UD, Biaxial, etc.)

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method 1)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tensile</td>
<td></td>
</tr>
<tr>
<td>— strength</td>
<td>ISO 527-1</td>
<td></td>
</tr>
<tr>
<td>— modulus</td>
<td>ISO 527-4 (specimen type 3)</td>
<td></td>
</tr>
<tr>
<td>— elongation</td>
<td>ISO 527-5 (specimen type A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Compressive</td>
<td>According to Table 7</td>
</tr>
<tr>
<td>— strength</td>
<td>ISO 14126 (method 1, specimen type A 2)</td>
<td></td>
</tr>
<tr>
<td>— modulus</td>
<td>ISO 14126 (method 1, specimen type A 2)</td>
<td></td>
</tr>
<tr>
<td>— failure strain</td>
<td>ISO 14126 (method 1, specimen type A 2)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Flexural</td>
<td></td>
</tr>
<tr>
<td>— strength</td>
<td>ISO 14125 (method A)</td>
<td></td>
</tr>
<tr>
<td>Fibre volume content</td>
<td>DIN EN 2564</td>
<td>50% ± 5</td>
</tr>
</tbody>
</table>

1) other standards may be agreed upon with the Society prior to testing
2) reduction of the free buckling length to 8 mm ± 0.25 mm is allowed

Table 7 Tensile, compressive and flexural testing of laminates made of fabrics 1)

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Unidirectional 0°</th>
<th>Biaxial ±45° or 0°/90°</th>
<th>Triaxial 0°/±45°</th>
<th>Quadraxial 0°/90°/±45°</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Tensile</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>— strength</td>
<td>MPa</td>
<td>1125</td>
<td>625</td>
<td>565</td>
<td>500</td>
</tr>
<tr>
<td>— modulus</td>
<td>GPa</td>
<td>100</td>
<td>55</td>
<td>45</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Compressive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>— strength</td>
<td>MPa</td>
<td>750</td>
<td>415</td>
<td>375</td>
<td>335</td>
</tr>
<tr>
<td>— modulus</td>
<td>GPa</td>
<td>87.5</td>
<td>48</td>
<td>44</td>
<td>40</td>
</tr>
</tbody>
</table>
### Table 8 Requirements for aramid reinforcements

<table>
<thead>
<tr>
<th>Property (1)</th>
<th>Test standard (2)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content</td>
<td>ISO 3344</td>
<td>msv</td>
</tr>
<tr>
<td>Mass per unit area</td>
<td>ISO 4605</td>
<td>mean ± 2 sdev, within manufacturer’s nominal value ±10%</td>
</tr>
<tr>
<td>Interlaminar shear strength (ILSS), Short-beam test</td>
<td>ISO 14130</td>
<td>mean - 2 sdev &gt; 25 MPa</td>
</tr>
</tbody>
</table>

1) unless otherwise agreed, all parameters shall be tested and documented in W certificate
2) other standards may be used if agreed upon with the Society prior to testing

### 4 Aramid fibre reinforcements

#### 4.1 General

**4.1.1** All aramid reinforcements shall comply with the requirements given in Table 8.

**4.1.2** The laminate to be tested in interlaminar shear shall be according to [4.3]. The test specimen shall be oriented in a direction parallel to the majority of the fibres when possible, or in the main direction of the reinforcement.

### 4.2 Tensile and compressive strength

**4.2.1** The tensile and compressive capacity of laminate made from the aramid reinforcement can be determined by testing according to Table 9.

#### Flexural

<table>
<thead>
<tr>
<th>flexural</th>
<th>MPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>900</td>
<td>500</td>
</tr>
<tr>
<td>400</td>
<td>365</td>
</tr>
</tbody>
</table>

1) these values refer to a fibre volume fraction of 50% ± 5%, a uniform lay-up and the 0° direction. Other parameters may be accepted if agreed upon with the Society prior to testing
4.2.2 The laminate to be tested shall be according to [4.3], and the tensile tests shall be performed in the main fibre directions of a fabric/weave.

Table 9 Tensile and compressive testing

<table>
<thead>
<tr>
<th>Property</th>
<th>Test standard 1)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile</td>
<td></td>
<td></td>
</tr>
<tr>
<td>strength</td>
<td>msmv, or m - 2 sdev</td>
<td></td>
</tr>
<tr>
<td>modulus</td>
<td></td>
<td>msv</td>
</tr>
<tr>
<td>elongation</td>
<td>ISO 527-1,4,5</td>
<td>msmv, or m - 2 sdev</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>strength</td>
<td>msmv, or m - 2 sdev</td>
<td></td>
</tr>
<tr>
<td>modulus</td>
<td></td>
<td>msv</td>
</tr>
<tr>
<td>elongation</td>
<td>ISO 14126</td>
<td>msmv, or m - 2 sdev</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) other standards may be used if agreed upon with the Society prior to testing

4.3 Laminate requirements

4.3.1 The laminate shall be made with a Society approved marine grade polyester, vinyl ester, or epoxy resin. The manufacturer may elect type of resin, but the testing will only be valid for the type of resin used, as well as resins with higher tensile strength and higher elongation at failure.

4.3.2 It is recommended that the laminate be cured at room temperature and atmospheric pressure. However, another curing cycle may be chosen by the manufacturer. It is recommended that a curing cycle that can be carried out at a production site is selected.

4.3.3 The laminate shall have a fibre volume fraction as specified by the reinforcement manufacturer. It is recommended that a fibre volume fraction obtainable at a production site is selected.

4.3.4 When laminated, the fibre reinforcement shall have moisture content at the maximum specified by the manufacturer, see Table 8.

4.3.5 In general, all layers of fabrics/weaves shall be oriented in the same direction in the laminate. Exceptions can be made if symmetric laminates are needed for testing. Such cases shall be discussed with the Society.

4.3.6 Test specimens shall be wide enough to cover at least four repeats of the structure of the weave/fabric.
5 Polyester and vinyl ester resins

5.1 Resin properties

5.1.1 The approval of polyester and vinyl ester are divided into the following quality grades:
— resin grade 1: quality with good water resistance
— resin grade 2: quality with normal water resistance
— fire retardant resin
— gelcoat and topcoat
— fire retardant gelcoat and topcoat.

5.1.2 The polyester and vinyl ester shall be suitable for the intended application (e.g. lamination by hand lay-up, spraying, resin transfer moulding, vacuum bagging method, etc.) They shall have good wetting properties and shall cure satisfactory at normal room temperature, or at other specified curing condition. Polyester and vinyl ester intended for other production methods may be approved after special consideration.

5.1.3 All additives (catalysts, accelerators, filling materials, colouring pigments etc.) shall be suitable for the thermosetting resin and shall be compatible with it as well as the other additives, such that a complete curing of the resin can be ensured.

5.1.4 Catalysts, which initiate the hardening process, and accelerators, which control the working time (pot life, gel-time) and the cure time, shall be used in accordance with the processing guidelines provided by the manufacturer. For cold-setting systems, catalysts shall be proportioned in such a way that complete curing is ensured between temperatures of 16°C and 25°C. Cold-setting systems that are to cure at temperatures outside of this range, as well as warm-curing systems, may be used after consultation with the Society.

5.1.5 Colouring pigments shall be climate-proof and consist of inorganic or non-fading organic dyes. The maximum permissible proportion shall not exceed the value specified by the manufacturer; if no value is specified, then it shall not exceed 5% by weight.

5.1.6 Requirements to production and quality control of the resin are given in Table 10, or alternatively an equivalent level shall be met.

5.1.7 Requirements for cured resin are given in Table 11. Comment: unless anything else is specified by the manufacturer, the following curing procedure shall be used:
— standard MEKP (active oxygen 9.0 - 9.2%)
— curing: 24 hours at 23°C
— post curing: 24 hours at 50°C.
Curing systems requiring high temperature may be approved after special consideration.

5.1.8 Resins containing waxes or other substances (like DCPD resins or blends of DCPD), which might lower external adhesive capacity shall be subjected to the delamination test according to Table 12.

Preparation of test piece:
1) a primary laminate consisting of five (5) layers of 450 g/m² emulsion/powder bounded mat with excess polyester in the upper surface. Curing procedure: 48 h at 23°C. The laminate surface shall not be covered
2) a secondary laminate consisting of five (5) layers of 450 g/m² emulsion/powder bounded mat is built on the first without any form of upper surface treatment. Curing procedure as selected in [5.1.7]. The fibre weight fraction shall be 50% ± 5%.

Preparation of reference piece:
1) a laminate consisting of ten (10) layers of 450 g/m² emulsion/powder bounded mat. Curing procedure as selected in [5.1.7].

### Table 10 Manufacturer's quality control for polyester and vinyl ester in liquid condition

<table>
<thead>
<tr>
<th>Control on</th>
<th>Test method 1)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>ISO 1675</td>
<td>msv</td>
</tr>
<tr>
<td>Viscosity 2)</td>
<td>ISO 2555 3)</td>
<td>msv ±250 mPas</td>
</tr>
<tr>
<td>Monomer content</td>
<td>ISO 3251</td>
<td>msv ± 2%</td>
</tr>
<tr>
<td>Mineral content 2)</td>
<td>DIN 16945, item 4.10</td>
<td>msv ± 1%</td>
</tr>
</tbody>
</table>
| Gel time 4)    | ISO 2535       | For curing time at room temperature:  
|                |                | < 60 minutes: msv ± 5 minutes  
|                |                | 60 to 120 minutes: msv ± 10 minutes  
|                |                | >120 minutes: msv ± 15 minutes |

1) other standards may be used if agreed upon with the Society prior to testing  
2) unless otherwise agreed, these parameters shall be tested and documented in W certificate  
3) for polyester and vinyl ester, the following parameters shall be used; Viscometer type A, rotational frequency 10, temperature 23°C. Viscosity can be accepted with msv ± 20%  
4) specify activator and initiator and % of each

### Table 11 Polyester and vinyl ester products, cured not reinforced resin

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method 1)</th>
<th>Acceptance criteria 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Grade 1</td>
<td>Grade 2</td>
</tr>
<tr>
<td>Volumetric curing shrinkage</td>
<td>ISO 3521</td>
<td>msv (%)</td>
</tr>
<tr>
<td>Ultimate tensile strength 3, 4)</td>
<td>ISO 527-1,2</td>
<td>mean minimum 55 MPa</td>
</tr>
<tr>
<td>Tensile modulus 4)</td>
<td>ISO 527-1,2</td>
<td>msv minimum 3000 MPa</td>
</tr>
<tr>
<td>Fracture elongation 4)</td>
<td>ISO 527-1,2</td>
<td>mean minimum 2.5%</td>
</tr>
<tr>
<td>Ultimate flexural strength</td>
<td>ISO 178</td>
<td>mean minimum 100 MPa</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>ISO 178</td>
<td>msv minimum 2700 MPa</td>
</tr>
<tr>
<td>Barcol hardness 4, 5)</td>
<td>EN 59</td>
<td>msv minimum 35</td>
</tr>
<tr>
<td>Heat deflection temperature</td>
<td>ISO 75-1,2</td>
<td>mean minimum 70°C</td>
</tr>
<tr>
<td>Water absorption 6)</td>
<td>ISO 62</td>
<td>mean maximum 80 mg</td>
</tr>
</tbody>
</table>

Non-metallic materials  
DNV GL AS
1) other standards may be used if agreed upon with the Society prior to testing
2) — *msv* verified to be within ± 10% of *m* of type test results
   — *msmv* verified to be below *m* - 2 sdev of type test results
3) test samples for tensile testing ISO 527-2/1B/50; test specimen 1B and test speed 50 mm/minute
4) unless otherwise agreed, these parameters shall be tested and documented in W certificate. Barcol hardness shall be measured on each specimen and shall comply with manufacturer’s specified value
5) resin may deviate from these values, provided a minimum value of 30 is met and the manufacturer can demonstrate adequate cure
6) test sample 50 x 50 x 4 mm (± 1 x 1 x 0.2). Distilled water. Exposure time 28 days at 23°C. Resin may deviate from these values, provided the water ageing properties are documented

### Table 12 Interlaminar strength of LSE resins, double cantilever beam test

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interlaminar fracture toughness, DCB</td>
<td>ASTM D5528, Mode 1 3)</td>
<td>Minimum 80% of mean strength in reference piece&lt;br&gt;The fracture shall not be a typical brittle fracture with smooth surfaces.</td>
</tr>
</tbody>
</table>

1) shall be tested and documented in W certificate, unless otherwise agreed<br>2) other standards may be used if agreed upon with the Society prior to testing<br>3) double cantilever beam test with high loading rate

### 5.2 Fire retardant resin properties

#### 5.2.1 polyester and vinyl ester can be approved as fire retardant qualities provided they are in compliance with the following:

— the hull and canopy material shall be flame tested to determine its fire-retarding characteristics by placing a test specimen in a flame. After removal from the flame the burning time and burning distance shall be measured and shall be to the satisfaction of the administration (IMO Res. A.689(17) Part 1, 6.2.1)

— the finished resin, including all fillers, shall fulfil the requirements for liquid resin in Table 10, and cured resin in Table 12, grade 2 and the requirements to combustibility in Table 13

— a finished resin with water absorption of 100 to 150 mg per test sample may be approved after special consideration (shall be evaluated with basis in blistering test and testing of laminate properties after aging at elevated temperature).

### Table 13 Combustibility testing of fire retardant resins

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method 1)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustibility 2)</td>
<td>ASTM D2863</td>
<td>Oxygen index minimum 23</td>
</tr>
<tr>
<td>Fire retardant test 3)</td>
<td>ISO 5660-1, Cone calorimeter method&lt;br&gt;Also ref. LSA Code, MSC/Circ.1006</td>
<td>Average ignition time &gt; 40 s</td>
</tr>
<tr>
<td></td>
<td>LSA Code, MSC/Circ.1006</td>
<td>Area of flame impingement shall not support combustion more than 30 sec. after being removed from the burner</td>
</tr>
</tbody>
</table>
5.3 Gelcoat and topcoat properties

5.3.1 Gel coat and topcoat shall be produced of base polyester that fulfils the requirements in [5.1], grade 1 and Table 14.

Table 14 Properties of gelcoat/topcoat

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method 1)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture elongation</td>
<td>ISO 527-1,2 2)</td>
<td>Minimum 3.0%</td>
</tr>
<tr>
<td>Covering</td>
<td></td>
<td>Complete covering shall be achieved within a thickness of maximum 400 μm of cured resin</td>
</tr>
</tbody>
</table>

5.4 Fire retardant gelcoat and topcoat properties

5.4.1 Fire retardant gel-coat and topcoat shall be produced of base resin that fulfils the requirements to fire retardant resins in [5.2] and shall be able to withstand long term exposure to weathering without any visible signs of crazing, outwash of matter or significant colour change.

6 Epoxy Resin Systems

6.1 General

6.1.1 Epoxy resin system is in the context of this set of rules defined as: “Cured, non-reinforced, 2-component material based on a specified epoxy resin (modified or non-modified A component) cross-linked by a specified curing agent (B component, based on amine, amide, etc.).”

6.1.2 Compatibility shall be demonstrated for the combination of gelcoat and laminating resin if the basic formulations of the resins are not the same.

6.1.3 The epoxy resin systems shall be suitable for the intended application (e.g. lamination by hand lay-up, spraying, resin transfer moulding, vacuum bagging method, etc.) Laminating resins shall have good impregnation characteristics when being processed. In a cured stage, they shall be resistant to fuels, river and sea water, and shall exhibit a high resistance to ageing. Furthermore, adequate resistance to hydrolysis shall be ensured when used with permissible additives and filling materials.

6.2 Quality control

6.2.1 The extent of the manufacturer's quality control during production shall as a minimum be as listed in Table 15 to ensure consistent product quality. The manufacturer shall carry out delivery testing of each consignment and measured values shall be filed and made available to the surveyor.

1) other standards may be used if agreed upon with the Society prior to testing
2) shall be tested and documented in W certificate, unless otherwise agreed
3) laminates to be prepared as per LSA Code, MSC/Circ.1006
Table 15 Manufacturer’s quality control 1)

<table>
<thead>
<tr>
<th>Control on 2)</th>
<th>Test method 2)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy equivalent</td>
<td>ISO 3001</td>
<td>msv (g/mol)</td>
</tr>
<tr>
<td>Viscosity</td>
<td>ISO 3219</td>
<td>msv (mPas) ± 20%</td>
</tr>
<tr>
<td>Density</td>
<td>ISO 1675</td>
<td>msv (g/cm$^3$)</td>
</tr>
<tr>
<td>Gel Time (temperature increase)</td>
<td>DIN16945, section 6.26.3, DIN EN ISO 2535</td>
<td>msv</td>
</tr>
</tbody>
</table>

1) the table is relevant for both epoxy resin (A component) and curing agent (B component) in liquid condition, separately, for the basic epoxy resin system and each of any variants, ref. ISO 3673-1, Table 1
2) unless otherwise agreed, all parameters shall be tested and documented in W certificate
3) other standards may be used if agreed upon with the Society prior to testing

6.3 Requirements for curing

6.3.1 Requirements for cured resin are given in Table 16. Unless otherwise agreed, the curing time and temperature shall be:
— 7 days at 23°C (normally considered to be full curing)
— curing procedures requiring higher temperature or longer time for full curing may be approved upon special consideration
— the manufacturer shall specify a curing procedure giving properties that can realistically be achieved at a production site.

Table 16 Testing of mechanical properties of the cured epoxy system 1)

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method 2)</th>
<th>Acceptance criteria 3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volumetric curing shrinkage</td>
<td>ISO 3521</td>
<td>msv</td>
</tr>
<tr>
<td>Tensile strength 4, 5)</td>
<td>ISO 527-1,2</td>
<td>mean min. 55</td>
</tr>
<tr>
<td>Tensile modulus 5)</td>
<td>ISO 527-1,2</td>
<td>msv min. 2700</td>
</tr>
<tr>
<td>Fracture elongation 5)</td>
<td>ISO 527-1,2</td>
<td>mean min. 2.5</td>
</tr>
<tr>
<td>Ultimate flexural strength</td>
<td>ISO 178</td>
<td>mean min. 100</td>
</tr>
<tr>
<td>Flexural modulus</td>
<td>ISO 178</td>
<td>msv min. 2700</td>
</tr>
<tr>
<td>Heat deflection temperature, HDT</td>
<td>ISO 75-1,2</td>
<td>mean min. 65</td>
</tr>
<tr>
<td>Water absorption 6)</td>
<td>ISO 62</td>
<td>mean max. 65</td>
</tr>
</tbody>
</table>
1) the table applies to components A + B mixed and fully cured, see. ISO 3673-2, Table 2
2) other standards may be agreed upon with the Society prior to testing
3) — msv verified to be within ± 10% of m of type test results
   — msmv verified to be below m - 2 sdev of type test results
4) test samples for tensile testing ISO 527-2/1B/50; test specimen 1B and test speed 2 to 5 mm/min
5) unless otherwise agreed, these parameters shall be tested and documented in W certificate
6) test sample 50 x 50 x 4 mm (± 1 x 1 x 0.2). Distilled water. Exposure time 7 days at 23°C. Resin may deviate from these values, provided the water ageing properties are documented

6.4 Fire retardant qualities

6.4.1 Epoxy resin systems can be approved as fire retardant qualities provided they are in compliance with the following:
— the hull and canopy material have been flame tested to determine its fire-retarding characteristics by placing a test specimen in a flame. After removal from the flame the burning time and burning distance have been measured and the documented test results are to the satisfaction of the administration (IMO Res. A.689(17) Part 1, 6.2.1).

6.4.2 The finally mixed and fully cured resin (A + B components) including all fillers shall comply with the requirements for liquid resin in Table 15, or be on an equivalent level. Cured epoxy materials shall comply with the requirements in Table 16.

6.4.3 Fire-retardant epoxy systems shall comply with the requirements in Table 17.

Table 17 Testing of fire retardant epoxy system (solid material)

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Combustibility 1)</td>
<td>ASTM D2863 or equivalent standard</td>
<td>Oxygen index min. 23</td>
</tr>
<tr>
<td>Fire retardant test 2)</td>
<td>ISO 5660-1, Cone calorimeter method</td>
<td>Average ignition time &gt; 40 s</td>
</tr>
<tr>
<td></td>
<td>Also ref. LSA Code, MSC/Circ.1006</td>
<td></td>
</tr>
<tr>
<td></td>
<td>LSA Code, MSC/Circ.1006</td>
<td>Area of flame impingement shall not support combustion more than 30 s after being removed from the burner</td>
</tr>
</tbody>
</table>

1) unless otherwise agreed, this parameters shall be tested and documented in W certificate
2) laminates to be prepared as per LSA Code, MSC/Circ. 1006

7 Prepreg materials

7.1 General requirements

7.1.1 Prepreg materials shall be characterised with fibre types and resin types used, as well as fiberweight fraction, fiber tex, sizing, ply weight and thickness.

7.1.2 The extent of the manufacturer’s quality control during production shall be suitable to ensure consistent product quality. The manufacturer shall carry out delivery testing of each consignment and measured values shall be filed and made available to the surveyor.
7.1.3 Curing cycle and conditions shall be in accordance with manufacturer’s recommendations. It is recommended that a curing cycle which can be carried out at a production site is selected.

7.2 Properties

7.2.1 Requirements to testing of cured prepreg properties are given in Table 18.

Tensile and compressive strength, tensile and compressive modulus, and tensile fracture elongation shall be tested in the prepreg’s main directions, 0° and 90° (alternatively other main fiber directions, X°).

Table 18 Requirements to testing of prepreg materials

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method 1)</th>
<th>Acceptance criteria 2)</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prepreg weight 3)</td>
<td>-</td>
<td>&lt; ± 3% of value on datasheet</td>
<td>msv or mean</td>
</tr>
<tr>
<td>Fibre weight fraction 3)</td>
<td>ASTM D3171</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISO 1172 4)</td>
<td>&lt; ± 3% of value on datasheet</td>
<td>msv or mean</td>
</tr>
<tr>
<td>Tensile strength 0° and 90° (or X°) 3)</td>
<td>ASTM D3039</td>
<td>To be agreed with the Society prior to testing</td>
<td>msv or m-2sdev</td>
</tr>
<tr>
<td></td>
<td>ISO 527</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tensile modulus 0° and 90° (or X°) 3)</td>
<td>ASTM D3039</td>
<td>To be agreed with the Society prior to testing</td>
<td>msv or mean</td>
</tr>
<tr>
<td></td>
<td>ISO 527</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fracture elongation 0° and 90° (or X°) 3)</td>
<td>ASTM D3039</td>
<td>To be agreed with the Society prior to testing</td>
<td>msv or m-2sdev</td>
</tr>
<tr>
<td></td>
<td>ISO 527</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Poisson ratio 0° and 90° (or X°)</td>
<td>ASTM D3039</td>
<td>To be agreed with the Society prior to testing</td>
<td>msv or m-2sdev</td>
</tr>
<tr>
<td></td>
<td>ISO 527</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive strength 0° and 90° (or X°)</td>
<td>ASTM D3410</td>
<td>To be agreed with the Society prior to testing</td>
<td>msv or m-2sdev</td>
</tr>
<tr>
<td></td>
<td>ASTM D695</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISO 14126</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressive modulus 0° and 90° (or X°)</td>
<td>ASTM D3410</td>
<td>To be agreed with the Society prior to testing</td>
<td>msv or m-2sdev</td>
</tr>
<tr>
<td></td>
<td>ASTM D695</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISO 14126</td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-plane shear strength</td>
<td>ASTM D5379</td>
<td>To be agreed with the Society prior to testing</td>
<td>msv or m-2sdev</td>
</tr>
<tr>
<td></td>
<td>ISO 14129</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interlaminar shear strength (ILSS), Short-Beam Test 3)</td>
<td>ASTM D2344</td>
<td>To be agreed with the Society prior to testing</td>
<td>msv or m-2sdev</td>
</tr>
<tr>
<td></td>
<td>ISO 14130</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water retention strength</td>
<td>Interlaminar shear after 1000 hrs in salt water acc. to DIN 50905 at 40°C</td>
<td>&lt; 10% strength reduction</td>
<td>msv or mean</td>
</tr>
<tr>
<td>Glass transition temperature 3)</td>
<td>ASTM E1545</td>
<td>min. 70°C</td>
<td>msv or mean</td>
</tr>
</tbody>
</table>


Non-metallic materials

DNV GL AS
8 Sandwich core materials

8.1 General requirements

8.1.1 Core materials shall have stable long time properties; continuous chemical processes, diffusion, etc. and shall not affect the physical properties of the material. If considered necessary, documentation may be required.

8.1.2 On delivery the surface of the material shall, if not otherwise agreed, be such that no further machining or grinding is required to obtain proper bonding of the material. If however surface treatment is required, this shall be stated by the manufacturer.

8.1.3 The test methods described consider most grades of closed cell polymeric foams and end grain balsa core. For core materials of particular composition or structure, e.g. honeycombs, other/additional requirements may be introduced.

8.1.4 Core materials shall be compatible with resins based on polyester, vinyl ester and epoxy. Core materials with a limited compatibility may be accepted upon special consideration. Limitations shall be stated by the manufacturer.

8.1.5 The approval will be related to a set of physical properties, which will be stated in the type approval certificate. The minimum properties shall be specified by the manufacturer and verified by the approval testing.

8.2 Requirements to all core materials (closed cell foams)

8.2.1 The requirements applicable for all core materials made of closed cell foam are stated below and in Table 19. Further details regarding requirements for testing/documentation are stated in the relevant type approval programme.

8.2.2 Density: The manufacturer shall specify a “Manufacturer’s Specified Minimum Value” (msmv) which is confirmed by the test results.

8.2.3 Water absorption
The two sides of the cube that face the laminate skins shall be sealed with resin. The manufacturer shall specify a “Manufacturer’s Specified Minimum Value” (msmv) which is confirmed by the test results.

8.2.4 Tensile properties
The tensile tests shall be performed in the through thickness direction of the core. For very anisotropic materials, the Society may require additional tests in other directions. The core material shall be laminated with:
— a standard ortho polyester, and/or
— a resin with better adhesion properties. In such cases, the approval will be limited to the resin type used and resins with better adhesion properties. If the selected resin is temperature sensitive, e.g. rubberised, the Society may require testing at +50°C and −10°C.

The resin type used shall be stated in the test report.

The laminated core may then be glued or laminated to the test fixtures. Testing rate: Maximum speed of deformation, in mm/minute shall be 10% of the value of the measured initial thickness. The tensile properties shall be taken as the measured value irrespective of if the failure is in the core or in the core resin interface. Elongation shall be measured with extensometer on the core and secant modulus to be established.

The manufacturer shall specify a “manufacturer’s specified minimum value” (msmv) which is confirmed by the test results.

8.2.5 Compression testing

The compression tests shall be performed in the through thickness direction of the core. For very anisotropic materials the Society may require additional tests in other directions.

The cell walls at the loaded surfaces shall be stabilised with a suitable resin. Testing rate: Maximum speed of deformation, in mm/minute shall be 10% of the value of the measured initial thickness. Compression shall be measured with extensometer and secant modulus to be established.

The manufacturer shall specify a “manufacturer’s specified minimum value” (msmv) which is confirmed by the test results.

8.2.6 Block shear testing:

The shear strength, modulus and elongation shall be determined by block shear testing according to ISO 1922.

8.2.7 Four point bend shear testing

In order to ensure that the tensile strength of the core and of the core/skin interface is proportionate to the shear strength, the core variant with the highest density within each grade shall be tested in four point bend according to ASTM C393.

Scored core material of the highest density variant and greatest thickness delivered, shall be laminated with the following lay-up:

— 200 g/m² CSM at the core skin interface
— subsequent layers of 800/100 g/m² WR/CSM combimat or 200 g/m² CSM.

The total thickness of each skin laminate shall not exceed 10% of the core thickness. The fibre weight fraction shall be 50% + 5%.

The manufacturer may select to use:

— a standard ortho polyester, and/or
— a resin with better adhesion properties. In such cases, the approval will be limited to the resin type used and resins with better adhesion properties. If the selected resin is temperature sensitive, e.g. rubberised, the Society may require testing at +50°C and −10°C.

The resin type used shall be stated in the test report, and will be printed on the type approval certificate.

The manufacturer may elect to fill the scores with resin, or a sandwich adhesive. In this case, this will be stated on the type approval as a condition of use.

The shear strength obtained from the four point bend test, calculated according to [8.2.6], shall confirm the data from the block shear testing.

If the shear strength value obtained from the four point bend test is lower than the value obtained from the block shear testing, the manufacturer may elect to:

a) retest with another resin, or
b) the obtained value is used as the basis for approval, and the value will be printed on the type approval certificate. The shear modulus calculated according to [8.2.6] shall be based on the new shear strength.

In such cases, the core variant with the next lower density shall be tested in the same manner.
8.2.8 Heat resistance temperature
Heat resistance temperature is defined as the temperature at which either:
— shear strength, or
— shear modulus
has decreased by 20%.
The heat resistance temperature shall be specified by the manufacturer, and shall be greater than +45°C.
The heat resistance temperature shall be confirmed by four point bend testing the highest density core at
the specified temperature according to [8.2.7], where the shear strength and modulus shall be > 80% of the
results obtained in [8.2.7].

8.2.9 Water resistance
Water resistance is defined as the loss of shear strength and stiffness after conditioning in salt water (DIN 50905) at 40°C for four weeks.
The water resistance shall be confirmed by four point bend testing the highest and lowest density variant
according to [8.2.7], where the shear strength and modulus shall be > 80% of the results obtained in [8.2.7].

Table 19 General requirements for all core materials

<table>
<thead>
<tr>
<th>Reference</th>
<th>Property</th>
<th>Test method 1)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>[8.2.2]</td>
<td>Density for materials with sdev/mean &lt; 5% 2)</td>
<td>ISO 845</td>
<td>msmv in kg/m³</td>
</tr>
<tr>
<td></td>
<td>Density for materials with sdev/mean &gt; 5%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[8.2.3]</td>
<td>Water absorption</td>
<td>ISO 2896 Duration: 1 week in salt water (DIN 50905) at 40°C</td>
<td>1.5 kg/m²</td>
</tr>
<tr>
<td>[8.2.4]</td>
<td>Tensile - strength</td>
<td>ASTM C297</td>
<td>m - 2 sdev &gt; 1.6 msmv shear strength in MPa</td>
</tr>
<tr>
<td></td>
<td>Tensile - modulus</td>
<td></td>
<td>mean &gt; 1.7 msv shear modulus in MPa</td>
</tr>
<tr>
<td>[8.2.5]</td>
<td>Compressive - strength</td>
<td>ISO 844</td>
<td>m - 2 sdev &gt; 1.0 msmv shear strength in MPa</td>
</tr>
<tr>
<td></td>
<td>Compressive - modulus</td>
<td></td>
<td>mean &gt; 2.5 msv shear modulus in MPa</td>
</tr>
<tr>
<td>[8.2.6]</td>
<td>Block shear - strength 2)</td>
<td>ISO 1922</td>
<td>msmv &gt; 0.4 MPa</td>
</tr>
<tr>
<td></td>
<td>Block shear - modulus 2)</td>
<td></td>
<td>msv &gt; 9 MPa</td>
</tr>
<tr>
<td></td>
<td>Block shear - elongation</td>
<td></td>
<td>msv</td>
</tr>
<tr>
<td>[8.2.7]</td>
<td>Four point bend shear - strength</td>
<td>ASTM C393</td>
<td>±10% of msmv shear strength</td>
</tr>
<tr>
<td>[8.2.8]</td>
<td>Heat resistance - strength</td>
<td>Conditioned to heat resistance temperature, then ASTM C393</td>
<td>all values &gt; 80% of msmv shear strength</td>
</tr>
<tr>
<td></td>
<td>Heat resistance - modulus</td>
<td></td>
<td>mean &gt; 80% of msv shear modulus</td>
</tr>
<tr>
<td>[8.2.9]</td>
<td>Water resistance - strength</td>
<td>Conditioning: 4 weeks in salt water (DIN 50905) at 40°C, then ASTM C393</td>
<td>all values &gt; 80% of msmv shear strength</td>
</tr>
<tr>
<td></td>
<td>Water resistance - modulus</td>
<td></td>
<td>mean &gt; 80% of msv shear modulus</td>
</tr>
</tbody>
</table>
8.3 Core materials in slamming exposed areas

8.3.1 The requirements applicable to core material intended for use in slamming exposed areas are given in [8.3.2] to [8.3.7]. Further details regarding requirements for testing or documentation are stated in the relevant type approval programme. It will be stated in the certificate whether the material properties with respect to slamming have been determined or not.

8.3.2 Scored core material of the lowest and highest density variant and greatest thickness delivered shall be tested in four point bend according to ASTM C393, at a high loading (i.e. slamming) rate.

8.3.3 The test specimen, i.e. the sandwich beam, shall include a longitudinal (sandwich) adhesive joint between two core material planks. The approval is valid for the (sandwich) adhesive used, and for (sandwich) adhesives with greater shear elongation at 0°C. The (sandwich) adhesive type used shall be stated in the test report.

8.3.4 The core material shall be laminated with the following lay-up:
- 200 g/m² CSM at the core skin interface
- subsequent layers of 800/100 g/m² WR/CSM combimat or 200 g/m² CSM.

The total thickness of each skin laminate shall not exceed 10% of the core thickness. The fibre weight fraction shall be 50% + 5%. The manufacturer may elect to use:
- standard ortho polyester, and/or
- a resin with better adhesion properties. In such cases, the approval will be limited to the resin type used and resins with better adhesion properties. If the selected resin is temperature sensitive, e.g. rubberised, the Society may require testing at +50°C and -10°C.

The resin type used shall be stated in the test report.

8.3.5 The manufacturer may elect to fill the scores with resin, or a sandwich adhesive. In this case this shall be stated.

8.3.6 The sandwich beam shall be loaded at a rate of \( \frac{d\tau}{dt} = 65 \text{ MPa s}^{-1} \).

8.3.7 The shear strength obtained from the four point bend test at slamming rate, shall confirm the data from the block shear testing determined in [8.2.6].

8.4 Core materials in fatigue exposed areas

8.4.1 The requirements applicable to core material intended for use in slamming fatigue exposed areas are given in [8.4.2] to [8.4.7]. Further details regarding testing or documentation are stated in the relevant type approval programme. It will be stated in the certificate whether the material properties with respect to fatigue have been determined or not.

8.4.2 Scored core material of the lowest and highest density variant and greatest thickness delivered shall be fatigue tested in four point bend according to ASTM C393.

8.4.3 The test specimen, i.e. the sandwich beam, shall include a longitudinal (sandwich) adhesive joint between two core material planks. The approval is valid for the (sandwich) adhesive use, and for (sandwich) adhesives with greater shear elongation at 0°C. The (sandwich) adhesive type used shall be stated in the test report.
8.4.4 The core material shall be laminated with the following lay-up:
— 200 g/m⁴ CSM at the core skin interface
— subsequent layers of 800/100 g/m² WR/CSM combimat or 200 g/m² CSM.
The total thickness of each skin laminate shall not exceed 10% of the core thickness. The fibre weight fraction shall be 50% + 5%. The manufacturer may elect to:
— a standard ortho polyester, and/or
— a resin with better adhesion properties. In such cases, the approval will be limited to the resin type used and resins with better adhesion properties. If the selected resin is temperature sensitive, e.g. rubberised, the Society may require testing at +50°C and -10°C.
The resin type used shall be stated in the test report.

8.4.5 The manufacturer may select to fill the scores with resin, or a sandwich adhesive. In this case this shall be stated.

8.4.6 The sandwich beam shall be load cycled between 5% and 50% of the manufacturer’s specified minimum shear strength for each density variant, \( \tau_{msmv} \), for \( 10^5 \) cycles. The test machine shall be run in load control. The loading/de-loading rate shall be \( \frac{d\tau}{dt} = 65 \text{ MPa s}^{-1} \), but a cooling period between loadings, up to a period of 0.1 sec. will be allowed.

8.4.7 After fatigue testing, the residual strength of the beams shall be determined by testing according to [8.2.7]. The shear strength and modulus shall be > 80% of the results obtained in [8.2.7].

8.5 Requirements to cross-cut balsa wood

8.5.1 Cross-cut or cross-grained wood is timber which has been cut-cross the grain.

8.5.2 For material approval, the basic conditions given in Sec.1 shall apply.

8.5.3 A general description of the core material shall be provided. The following details are required for a general description:
— commercial name
— treatment of the wood
— storage conditions.

8.5.4 The properties given in Table 20 shall be documented. The tested values will be stated on the type approval certificate.

Table 20 Requirements for balsa wood core materials

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw density</td>
<td>DIN 5218, 3 samples</td>
<td>min. 96 kg/m³ *</td>
</tr>
<tr>
<td>Moisture content</td>
<td>ISO 3130, 3 samples</td>
<td>12 ± 2% *</td>
</tr>
<tr>
<td>Compressive strength II, #</td>
<td>DIN 5218, 6 samples</td>
<td>II, min. 5.0 MPa #, min. 0.4 MPa</td>
</tr>
<tr>
<td>Modulus of elasticity II, #</td>
<td>DIN 5218, 6 samples</td>
<td>II, min. 2275 MPa #, min. 35 MPa</td>
</tr>
<tr>
<td>Shear strength</td>
<td>DIN 5329, 6 samples</td>
<td>min. 1.1 MPa *</td>
</tr>
</tbody>
</table>
Shear modulus  | DIN 5329, 6 samples | min. 105 MPa

II is parallel to the grain, and

# is perpendicular to the grain of the wood

1) other standards may be used if agreed upon with the Society prior to testing

* unless otherwise agreed, these shall be tested and documented in W certificate.

8.5.5 The tests shall be performed on samples which exhibit none of the flaws which are still permissible for processing. The surfaces must be plane and sanded. As the testing environment, the standard climate 23/50 (23°C / 50% relative humidity) shall be used.

9 Sandwich adhesives

9.1 Properties

9.1.1 The approval of sandwich adhesives are divided into two different quality grades:

Grade 1 = required quality of sandwich adhesives for hull constructions

Grade 2 = required quality of sandwich adhesives for less critical applications.

9.1.2 The approval will be related to a set of physical properties which will be specified in the type approval certificate. The minimum properties shall be specified by the manufacturer and verified by the approval testing. The properties to be specified on the certificate are given in Table 21 and Table 22.

9.1.3 Requirements for production and quality control of the sandwich adhesive are given in Table 21.

9.1.4 Requirements for cured material in the joint are given in Table 22.

9.1.5 Curing conditions shall be according to the manufacturer’s specifications, preferably at temperatures obtainable in a yard. Detailed description of surface treatment and application procedure is required.

9.1.6 Heat resistance temperature is defined as the temperature at which flatwise tensile strength has decreased to 80% of room temperature strength.

The heat resistance temperature shall be specified by the manufacturer, and shall be greater than + 45°C. The heat resistance temperature shall be confirmed by testing according to flatwise tensile testing at the specified temperature, where the flatwise tensile strength shall be > 80% of the results obtained at room temperature.

For testing of shear and flatwise tension, the test samples shall be made of two pieces of high density core material (preferably PVC foam) with the sandwich adhesive located in the midplane parallel to the steel supports. The adhesive layer shall be > 1 mm thick.

Table 21 Quality control for sandwich adhesives

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>ISO 1675</td>
<td>msv ± 10%</td>
</tr>
<tr>
<td>Viscosity</td>
<td>ASTM D1084, method B (for free-flowing adhesives)</td>
<td>msv ± 20%</td>
</tr>
</tbody>
</table>
### Table 22 Sandwich adhesives

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method 1)</th>
<th>Acceptance criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Grade 1</td>
</tr>
<tr>
<td>Overall volume shrinkage</td>
<td>ISO 3521 2)</td>
<td>msv</td>
</tr>
<tr>
<td>Flatwise tensile strength</td>
<td>ASTM C297 (Specimen: 5 x 5 cm, speed: 1 mm/minute) 3)</td>
<td>msv minimum 1.0 (MPa)</td>
</tr>
<tr>
<td></td>
<td>At 23°C:</td>
<td>All values &gt; 80% of msv at 23°C</td>
</tr>
<tr>
<td></td>
<td>At heat resistance temperature</td>
<td></td>
</tr>
<tr>
<td>Heat resistance</td>
<td>Conditioned to heat resistance temperature, then flatwise tensile testing according to ASTM C297</td>
<td>minimum 45°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>All values &gt; 80% of msv at 23°C</td>
</tr>
<tr>
<td>Tensile strength</td>
<td>ISO 527-1,2 (Specimen thickness 4 mm)</td>
<td>msv (MPa)</td>
</tr>
<tr>
<td>Fracture elongation 4)</td>
<td>At -10°C, 23°C and at heat resistance temperature</td>
<td>msv at 23°C: minimum 3.5%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>at -10°C: minimum 2.0%</td>
</tr>
<tr>
<td>Shear strength</td>
<td>ISO 1922 (23°C) 3)</td>
<td>msv minimum 0.4 (MPa)</td>
</tr>
<tr>
<td>Water resistance</td>
<td>4 weeks immersion in salt water (DIN 50905) at 40°C. Flatwise tensile testing according to ASTM C297 (Specimen: 5 x 5 cm, speed: 1 mm/minute, minimum 23°C)</td>
<td>minimum 80% retained strength after immersion</td>
</tr>
</tbody>
</table>

1) other standards may be used if agreed upon with the Society prior to testing
2) curing shrinkage is relevant only for gap filling fillers
3) the test samples shall be made of two pieces of high density core material (preferably PVC foam) with the sandwich adhesive located in the mid plane parallel to the steel supports. The adhesive layer shall be > 1 mm thick
4) approval may be refused for materials considered having a too low fracture elongation

* unless otherwise agreed, these shall be tested and documented in W certificate

---

## 10 Adhesives

### 10.1 General

**10.1.1** Stress patterns in adhesive joints are highly sensitive to joint geometry. The performance of an adhesive is thus highly dependent on many factors including but not limited to the type of joint and loading as well as choice of materials.

Requirements have been defined for the following classes of adhesives:

— **rigid adhesives**: high strength adhesives with high stiffness, one typical example are high performance epoxy adhesives
— flexible adhesives: have low strength, low stiffness and high strain to failure, one typical example is polyurethane adhesives
— sealants: are very similar to flexible adhesives with the only exception that they are not meant to transfer loads or moments.

10.2 Requirements to rigid adhesives

10.2.1 A general description of the adhesive shall be provided. Basic properties of the cured adhesive shall be verified by the testing.

10.2.2 Properties of the uncured adhesives. In the processing state, the following information shall be provided:
— density, according to ISO 1675
— viscosity, according to ISO 3219.

In the case of two-component thermosetting resins which cure at room temperatures, the pot life, according to ISO 10364, shall also be indicated.

10.2.3 Properties in the cured state. Requirements to testing of rigid adhesives are given in Table 23. The following properties shall be verified:
— tensile lap-shear strength
— long-duration tensile lap-shear test
— tensile lap-shear test at elevated temperature
— peeling resistance
— dimensional stability under heat
— tensile test: Measure the tensile modulus $E_t$ and the Poisson’s ratio $\mu$
— measurement of pH: Measurement of pH to avoid corrosion problems later on in the joint
— shear modulus ($G$): Shear modulus ($G$) is calculated from Young’s Modulus and Poisson’s ratio according to:
\[
G = \frac{E}{2(1 + \mu)}
\]
— glass transition temperature, $T_g$: The glass transition temperature ($T_g$) of the adhesive shall be determined by Dynamic Mechanical Analysis (DMA).

Table 23 Requirements to rigid adhesives

<table>
<thead>
<tr>
<th>Property</th>
<th>Test conditions</th>
<th>Test method</th>
<th>Acceptance criteria, data format and unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile lap-shear test $^2$</td>
<td>At RT after 24 ± 1 h curing at 23°C and storage at 50% relative humidity $^3$</td>
<td>EN 1465</td>
<td>12 MPa</td>
</tr>
<tr>
<td>Tensile lap-shear test after immersion in water $^2$</td>
<td>At RT after 1000 ± 12 h storage in distilled water at 23°C</td>
<td>EN 1465</td>
<td>12 MPa</td>
</tr>
<tr>
<td>Tensile lap-shear test at elevated temperatures $^2$</td>
<td>At 50°C</td>
<td>EN 1465</td>
<td>12 MPa</td>
</tr>
</tbody>
</table>
10.3 Requirements to flexible adhesives

10.3.1 A general description of the adhesive shall be given. The fundamental properties of the cured adhesive shall be verified by the testing.

10.3.2 Grades of adhesives. The field of application of this chapter is limited to the bonding of structural components and load-bearing components which are integrated into the structure, as well as components of relevance to ship safety. Depending on the area of application, an adhesive approval according to class A or class B will be required. For better understanding, the areas of application for class A and B are given below by way of example:

**Class A:**
Bonded joints under increased mechanical stressing (high strength with medium compliance):
— panes of insulating glass, single-pane safety glass or laminated safety glass
— rails for fastening seats
— door frames.

*Class B:*
Bonded joints under medium mechanical stressing (high compliance with medium strength):
— transparent plastic sheets (single panes with dimensions under 0.5 m × 0.5 m)
— wind-break walls.

10.3.3 Requirements to testing of flexible adhesives are given in Table 24. The following properties shall be verified:
— *measurement of pH*: Measurement of pH to avoid corrosion problems later on in the joint
— *shear modulus (G)*: Shear modulus (G) is calculated from Young’s Modulus and Poisson’s ratio
— *glass transition temperature (T_g)*: The glass transition temperature (T_g) of the adhesive shall be determined according to ISO 6721-2.

### Table 24 Requirements to flexible adhesives

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Acceptance criteria, data format and unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Class A</td>
</tr>
<tr>
<td>Shore A</td>
<td>ISO 7619-1</td>
<td>≥ 45</td>
</tr>
<tr>
<td>Fracture strain at -20°C</td>
<td>DIN 53504</td>
<td>≥ 50%</td>
</tr>
<tr>
<td>Tensile stress at yield for +60°C</td>
<td>DIN 53504</td>
<td>≥ 1.5 MPa</td>
</tr>
<tr>
<td>Tear propagation resistance</td>
<td>ISO 34-1</td>
<td>≥ 4 N/mm</td>
</tr>
<tr>
<td>Tensile lap-shear strength</td>
<td>DIN EN 1465</td>
<td>≥ 2 MPa</td>
</tr>
<tr>
<td>Values for the long-term tensile lap-shear test at:</td>
<td>Based on DIN EN 1465</td>
<td>0.25 MPa (2)</td>
</tr>
<tr>
<td>23°C / 50% rel. humidity at 60°C</td>
<td></td>
<td>0.15 MPa (2)</td>
</tr>
<tr>
<td>Relaxation test after 90-day conditioning</td>
<td>Based on DIN EN 1465 and ISO 6270-2</td>
<td>Specified by manufacturer</td>
</tr>
<tr>
<td>Measurement of pH</td>
<td>Insert test specimen into test tube, fill with de-ionized water and close test tube. Store the test tube in a temperature chamber for 30 days at 40°C. Measure pH value using litmus paper</td>
<td>Document pH. If pH value is outside the allowed range, the adhesive joint must be protected against the impact of water. Acceptable levels of pH: — aluminium: pH 6 to pH 8 — polycarbonate: pH 4 to pH 10 — steel: always to be protected against the impact of water</td>
</tr>
<tr>
<td>Shear modulus, G</td>
<td>Calculate</td>
<td>MPa</td>
</tr>
<tr>
<td>Glass transition temperature (T_g)</td>
<td>ISO 6721-2</td>
<td>°C</td>
</tr>
</tbody>
</table>
1) other standards may be agreed upon with the Society prior to testing
2) no failure may take place within the long-duration shear tension tests. The strain-in creep values that are determined shall be specified versus the time

10.3.4 Ready to use condition. The following shall be stated for the ready-to use condition:
— density, according to ISO 1675
— pot-life for two-component products (100 g mixture in a beaker) at 10°C and 30% relative humidity (RH) and also at 30°C and 70% RH
— skin-forming time at 10°C and 30% RH and also at 30°C and 70% RH.

10.3.5 Curing process. For the curing process, the following shall be given:
— curing distance at 10°C / 30% RH and 30°C / 70% RH after 24 hours, and also after 3, 7 and 28 days, for single-component systems
— tensile stress at yield according to DIN 53504, measured after 24 hours, and 2, 4 and 7 days, for two-component systems. For one series, storage shall take place at 10°C and for the other at 30°C. Testing climate: 23°C / 50% RH
— volume shrinkage, e.g. according to DIN 52451.

The following shall be specified for the adhesive:
— shore A hardness, according to DIN 53505
— qualitative assessment of the resistance to certain media, e.g. against seawater, UV radiation, fuel, mineral oil, hydraulic fluid, grease, acid and alkaline solutions.

For the adhesive, the following properties shall be verified:
— modulus of torsional shear, according to DIN EN ISO 6721-2B (min. temperature range – 30°C to + 80°C)
— tensile stress at yield and fracture strain, according to DIN 53504 at minus 20°C, plus 60°C and standard climate (23°C and 50% RH)
— tear propagation resistance, according to DIN 53515 for the standard climate.

10.3.6 Bonded joints. The following shall be determined at bonded joints with an adhesive layer thickness of 3 mm for the standard climate (in deviation from DIN EN 1465, using test samples with a thickness of at least 10 mm shall be used, with an overlap length of 20 mm and a testing speed of 5 mm/min):
— tensile lap-shear test, according to DIN EN 1465
— a long-duration tensile lap-shear test (based on DIN EN 1465) shall be performed to determine the strain in creep. Here the samples shall be loaded with an average tensile lap shear stress of 0.25 MPa (class A) in a standard climate and with 0.15 MPa (class A) at 60°C for at least three months. These measurements can be performed in the manufacturer’s own laboratory, if the deformations occurring during the tensile lap-shear tests at 0.25 MPa (class A) and 0.15 MPa (class A) were specified by the accredited testing body and if these correspond to the manufacturer’s own measurements. In the case of adhesives for which an approval according to class B is sought, the manufacturer shall specify minimum properties for 23°C and 60°C, and verify them within the long-duration tensile lap shear test
— as part of a relaxation test (based on DIN EN 1465), the samples shall be stored for 90 days with a constant elongation of 30% (class B at RT) with conditioning according to DIN 50017-KFW. Temperature-related changes in elongation are permissible. In the case of adhesives for which approval according to class A is sought, a minimum property shall be specified by the manufacturer and verified within the relaxation test.

10.4 Requirements to sealants

10.4.1 A general description of the sealant shall be provided. Basic properties of the sealant shall be verified by the testing. Requirements to testing of sealants are given in Table 25.
10.4.2 Lap-Shear – constant elongation
Test specimens shall be tested in accordance with EN ISO 8340 with 10% and 30% extension, while weathered according to ASTM D1183-92 (procedure D, 4 times).
The test specimens shall be loaded to destruction after weathering.

10.4.3 Glass transition temperature, $T_g$
The glass transition temperature ($T_g$) of the adhesive shall be determined according to ASTM E1356-08 (Differential Scanning Calorimetry).

10.4.4 UV-Resistance
Test specimens shall be aged in QUV for a minimum of 500 hours. Both aged and un-aged specimens shall be tested according to DIN 53504 to determine the elongation at break.

10.4.5 Measurement of pH
Measurement of pH to avoid corrosion problems later on in the joint.

**Table 25 Requirements to sealants**

<table>
<thead>
<tr>
<th>Property</th>
<th>Test method</th>
<th>Acceptance criteria, data format and unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lap shear test – constant elongation</td>
<td>Test sample in accordance with EN ISO 8340 with 10% and 30% extension.</td>
<td>Acceptance criterion: adhesive failure occurs in less than 5% of the bonding area. MPa (mean)</td>
</tr>
<tr>
<td></td>
<td>Weathering according to ASTM D1183-92, Test cycle D new 28 days,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>tested to destruction after ageing</td>
<td></td>
</tr>
<tr>
<td>Glass transition temperature ($T_g$)</td>
<td>ASTM E1356-08</td>
<td>$^\circ$C</td>
</tr>
<tr>
<td>UV Resistance</td>
<td>DIN 53504, S-2 or ASTM D412 min. 500 hrs QUV 2)</td>
<td>Reduction in elongation at break &lt; 30% (compared to un-aged samples)</td>
</tr>
<tr>
<td>Measurement of pH</td>
<td>Insert test specimen into test tube, fill with de-ionized water and close test tube. Store the test tube in a temperature chamber for 30 days at 40$^\circ$C. Measure pH value using litmus paper</td>
<td>Document pH. If pH value is outside the allowed range, the adhesive joint must be protected against the impact water. Acceptable levels of pH: — aluminium: pH 6 to pH 8 — polycarbonate: pH 4 to pH 10 — steel: always to be protected against the impact of water</td>
</tr>
</tbody>
</table>

1) other standards may be agreed upon with the Society prior to testing
2) 2 mm thick sheet, die cut dumbbell-shaped specimen (ASTM D412 or DIN 53 504), aged in QUV
SECTION 3 MANUFACTURE OF PRODUCTS MADE OF FRP

1 General

1.1 Scope

1.1.1 In this section requirements related to the manufacturing, quality assurance and quality control of FRP structures are given. It shall be recognised by the production site (yard/workshop) that there are limited or no means for non-destructive examination of FRP structures available. The production site is therefore to recognise the importance of exercising a rigorous control of all steps of the fabrication to ascertain that the finished product complies with relevant specification(s).

1.1.2 The use of fabricating procedures differing from those specified in this section will be subject to special consideration.

1.1.3 Manufacture of FRP-components shall only be performed by workshops which are approved by the Society.

1.1.4 Adhesive processing workshops for bonding of structural components and load-bearing components which are integrated into the structure, as well as components of relevance to ship safety shall be approved by the Society.

2 Handling of raw materials

2.1 Storage

2.1.1 Storage premises shall be so equipped and arranged that the material supplier’s directions for storage and handling of the raw materials can be followed. Storage shall be arranged in such a way that the identification of the materials, their storage conditions and maximum period of storage (expiry date) as prescribed by the manufacturer are clearly visible. Materials whose duration of storage exceeds the expiry date shall be removed immediately from the stores.

2.1.2 Storage premises for reinforcement materials shall be kept dry and clean so that the raw material is not contaminated. The materials shall be stored in unbroken original packaging before being used. Materials on which the original packaging has been broken shall be adequately protected against contamination when stored again after use.

2.1.3 Reinforcement materials shall be stored at the same temperature and humidity as the workshop in which they are going to be used, unless otherwise agreed with the Society. If the storage temperature is not the same the material shall be acclimatized at the workshop temperature and humidity prior to being deployed. The time of acclimatisation shall be adequate for the amount of reinforcement. For unbroken packages the acclimatisation shall have duration of at least two days.

2.1.4 Resins, gelcoat, hardeners, additives etc. shall be stored according to the manufacturers recommendations as regards temperature, shelf life, etc. If no such instructions are provided, then they shall be stored in dark, dry rooms at a temperature between 10°C and 18°C. The temperature of the storage-rooms shall be recorded continuously by means of thermographs. Raw materials which are stored at temperatures lower than 18°C shall be acclimatised to the temperature of the workshop prior to being used. Tanks for resins etc. shall be handled during storage according to the manufacturer’s recommendations and equipped and arranged accordingly.
2.1.5 Core materials shall be stored dry and protected against contamination and mechanical damage. Core materials shall be stored at the same temperature as the workshop in which they are going to be used, unless otherwise agreed with the Society.

2.1.6 Core materials shall be stored in such a way that out-gassing of the material is ensured prior to being used. Outgassing shall be carried out according to the manufacturer’s recommendations. When new free surfaces are created in the material, e.g. by sanding, cutting or machining, proper outgassing shall be ensured again.

2.1.7 Prepreg materials shall be stored according to the manufacturer's recommendation. For prepreg materials stored in refrigerated conditions a log shall be carried for each package showing the time and at which temperature the package has been stored/used outside its normal storage conditions.

2.2 Manufacturing premises and conditions

2.2.1 Manufacturing premises shall be so equipped and arranged that the material supplier’s directions for handling the materials, the laminating process and curing conditions can be followed.

2.2.2 The manufacturing premises shall be free from dust and other contamination that may in any way impair the quality of the end product.

2.2.3 The air temperature in the moulding shops shall not be less than 18°C. The stipulated minimum temperature shall be attained at least 24 hours before commencement of lamination, and shall be maintainable regardless of the outdoor air temperature.

The temperature in the moulding shop shall not vary more than ±5°C. This limit can be exceeded provided it has no detrimental effect on the product and provided there is no risk for condensation of humidity.

2.2.4 The relative humidity of the air shall be kept so constant that condensation is avoided and shall not exceed 80%. A higher relative humidity can be accepted on a case by case basis provided an adequate margin against the risk for condensation of humidity is provided.

In areas where spray moulding is taking place, the air humidity shall not be less than 40%. The stipulated air humidity shall be maintainable regardless of outdoor air temperature and humidity. More stringent requirements to humidity shall be adhered to if recommended by the manufacturer.

2.2.5 Other manufacturing conditions may be accepted based on special agreement with the Society provided that condensation of humidity can be safely avoided.

2.2.6 Air temperature and relative humidity shall be recorded regularly and the records filed for a period of at least three years. In larger shops there shall be at least one thermohydrograph for each 1500 m² where lamination is carried out. The location of the instruments shall be such as to give representative measurement results.

2.2.7 Draught through doors, windows, etc. and direct sunlight is not acceptable in places where lamination and curing are in progress.

2.2.8 The ventilation plant shall be so arranged that the curing process is not negatively affected.

2.2.9 Sufficient scaffolding shall be arranged so that all lamination work can be carried out without operators standing on the core or on surfaces on which lamination work is taking place.

2.2.10 During lamination of larger constructions the temperature shall be recorded at least at two levels vertically in the workshop and the curing system shall be adjusted to compensate for possible temperature differences.
2.2.11 Prefabrication of panels and other components shall be carried out on tables, fixtures, etc. above the shop floor level. No fabrication shall be carried out on the shop floor.

3 Production procedures and workmanship

3.1 General

3.1.1 Raw materials for all structural members covered by the rules shall be of approved type following the requirements of the relevant type approval programme. The supplier’s directions for application of the materials shall be followed.

3.1.2 Specified procedures shall be implemented for all tasks with significance to the quality of the end product. Where necessary to exercise a satisfactory control of the quality, these procedures shall be documented in writing in controlled documents.

3.1.3 The reference direction of reinforcement shall after being laid not deviate from the specified by more than ±5°.

3.1.4 Adjacent sheets of reinforcement shall in the normal case overlap to give structural continuity. The overlap length shall be such that the shear capacity of the overlap is not smaller than the tensile strength (perpendicular to the overlap) of the overlapping plies. The shear strength of the matrix shall not be assumed larger than 8 MPa. A higher shear strength can be assumed subject to the approval of the Society. (E.g. for a 0/90° 1000 g/m² type glass reinforcement the overlap shall not be smaller than 30 mm). In areas of low utilisation, overlaps may be dispensed with subject to the approval of the Society. Overlaps shall be staggered through the thickness of the laminate. The distance between two overlaps in adjacent plies shall not be smaller than 100 mm.

3.1.5 Thickness changes in a laminate shall be tapered over a minimum distance equal to 10 times the difference in thickness.

3.1.6 Thickness changes in core materials shall be tapered over a minimum distance equal to 2 times the difference in thickness. A larger distance may be required to maintain structural continuity of the skins.

3.2 Sandwich lay-up

3.2.1 Sandwich constructions can be fabricated either by lamination on the core, application of the core against a wet laminate, by bonding the core against a cured skin laminate using a core adhesive, by resin transfer, or by resin transfer moulding of the core together with one or both of the skin laminates.

3.2.2 An efficient bond shall be obtained between the skin laminates and the core and between the individual core elements. The bond strength shall not be smaller than the tensile and shear strength of the core. The application of a light CSM between core and skin laminate may be advantageous in this respect.

3.2.3 Manufacturer’s recommended tools for cutting, grinding etc. of various types of core material shall be specified in the production procedure.

3.2.4 All joints between skin laminates and core and between the individual core elements shall be completely filled with resin, adhesive or filler material. The joint gap between core blocks should generally not be larger than 3 mm. Larger gaps may be accepted if necessary, based on the characteristics of the adhesive or filler (e.g. its viscosity) and the thickness of the core. For slamming exposed areas a larger gap width shall also be reflected in the qualification testing of the core material and the adhesive, i.e. during slamming testing, ref. Sec.2 and type approval programme for sandwich core materials, see Sec.2 [8.1.5].
3.2.5 Core materials with open cells in the surface, shall be impregnated with resin before it is applied to a wet laminate or before lamination on the core is commenced, unless otherwise agreed.

3.2.6 When the core is applied manually to a wet laminate the surface shall be reinforced with a chopped strand mat of 450 g/m² in plane surface and 600 g/m² in curved surfaces. If vacuum is applied for core bonding the surface mats may be dispensed with provided it is demonstrated in the qualification tests that an efficient bond between core and skin laminate is obtained.

3.2.7 If the core is built up by two or more layers of core and any form of resin transfer is used, arrangements shall be made to ensure proper resin transfer and filling between the core blocks. This should be achieved by scoring or holing the core blocks and by placing a reinforcement fabric between the core blocks to facilitate resin distribution.

3.2.8 Frameworks for core build up shall give the core sufficient support to ensure stable geometrical shape of the construction and a rigid basis for the lamination work.

3.2.9 When a prefabricated skin laminate is bonded to a sandwich core measures shall be taken to evacuate air from the surface between skin and core.

3.2.10 The core material shall be free from dust and other contamination before the skin laminates are applied or core elements are glued together. The moisture content shall be sufficiently low not to have any adverse effect on curing. The acceptable moisture content shall be specified by the manufacturer of the core material.

3.2.11 When vacuum-bagging or similar processes are used it shall be ensured that curing in the core adhesive has not been initiated before vacuum is applied.

3.3 Manual lamination

3.3.1 The reinforcement material shall be applied in the sequence stated on the approved plan(s).

3.3.2 The first laminate layer shall be applied as soon as possible after application of the gelcoat. A fibre mat or fabric with low weight per unit area and a high resin content shall be used (e.g. for glass fibres: a maximum of 450 g/m² and a maximum of 30% glass by weight). The mat can be dispensed with provided a satisfactory resistance against water can be ensured.

3.3.3 If the surface protection shall be achieved by providing a gelcoat, then the gelcoat resin compound shall be applied with a uniform thickness of between 0.4 and 0.6 mm, using a suitable process. Laminates made from epoxy usually have no gelcoat layers.

3.3.4 The resin shall be applied on each layer of reinforcement. Gas and air pockets shall be worked out of the laminate before the next layer is applied. Rolling of the layers shall be made carefully, paying special attention to sharp corners and transitions. The viscosity and gel-time of the resin shall be adequate to prevent drain-out of resin on vertical and inclined surfaces. The tools and methods used when working the laminate shall not damage the fibres.

3.3.5 The time interval between applications of each layer of reinforcement shall be within the limits specified by the resin supplier. For thicker laminates care shall be taken to ensure a time interval sufficiently large to avoid excessive heat generation.

3.3.6 Curing systems shall be selected with due regard to the reactivity of the resin and in accordance with the supplier’s recommendations. Heat release during curing shall be kept at a safe level in accordance with the material manufacturer’s recommendations. The quantity of curing agents shall be kept within the limits specified by the supplier.
3.3.7 After completion of lamination, polyester laminates shall cure for at least 48 hours at an air temperature of minimum +18°C. Curing at a higher temperature and a shorter curing time may be accepted on the basis of control of the curing rate. For other types of resins curing shall be carried out according to the specified cure cycle and according to the resin manufacturer’s recommendations.

3.4 Vacuum assisted resin transfer moulding (VARTM) and vacuum-bagging

3.4.1 Points of resin injection shall be located and opened and closed in a sequence such that complete filling of the mould without any air being trapped is ensured.

3.4.2 The resin shall be formulated, based on the resin manufacturer’s recommendations, such that an adequate viscosity and gel-time is obtained to enable filling of the complete mould and such that the maximum temperature during cure is kept within acceptable limits, e.g. with respect to the temperature sensitivity of core materials.

3.4.3 The pressure level (vacuum) in the mould shall be specified prior to infusion. The pressure shall be adequate to ensure adequate consolidation of the laminate and that the specified mechanical properties are reached and that the mould is properly filled. The pressure shall be maintained throughout the mould during the cure cycle of the laminate, at least past the point of maximum temperature in the laminate, and the specified hold time. The vacuum shall be monitored by the use of pressure gauges distributed throughout the mould such that a reliable indication of the pressure distribution is obtained. This means that pressure gauges shall be placed far away from vacuum suction points. Adequate means to locate and repair leakage shall be deployed.

3.5 Spray moulding

3.5.1 The term spray moulding is understood to mean the simultaneous deposit of resin and fiberglass reinforcement. Manufacturers using this method are subject to special approval.

3.5.2 When approval of the spray moulding process is considered, special attention will be paid to production arrangement, ventilation equipment, the manufacturer’s own quality control and other factors of significance to the quality of the finished product.

3.5.3 Spray moulding of structural members shall be carried out only by specially approved operators.

3.5.4 The equipment used for spray moulding shall give an even and homogenous build-up of the laminate. Any dosage devices shall ensure an even application of additives to the polyester resin. No fibres shall be shorter than 20 mm.

3.5.5 When spray moulding, there shall be an even application over the entire surface. Regular rolling out of the sprayed-on layers shall be carried out. Next to the gel-coat rolling out shall be done for max. 1.5 mm thickness of finished laminate thickness, subsequently for at least each 2.5 mm of finished laminate thickness. The rolling out shall be done thoroughly to ensure adequate compression and removal of gas and air pockets. Special care shall be taken at sharp transitions and corners.

3.6 Curing

Curing shall be carried out in accordance with manufacturer’s instructions.

3.6.1 Cure cycles shall be documented by temperature records.

3.6.2 For cure taking place at room temperature in the workshop the registrations made in the workshop are sufficient to document the cure cycle.
3.6.3 For cure at elevated temperature, fans with ample capacity shall be operated in the compartment in which the cure is carried out to ensure an even distribution of temperature. Continuous records of temperature throughout the complete cure cycle shall be provided. Recording points shall be distributed throughout out the length, width and height of the cure compartment to the extent necessary to verify that the temperature distribution is even.

4 Bonding

4.1 Secondary bonding

4.1.1 A secondary bonding is defined as any bond between two FRP structures which is made after one or both of the individual structures has effectively cured.

4.1.2 The surface ply of a laminate subject to secondary bonding and the first ply of the bonding laminate shall be of chopped strand mat, unless otherwise agreed. This mat can be dispensed with provided the necessary bond strength is reached.

4.1.3 Surfaces in way of secondary bonding shall be clean and free from dust and other forms of contamination.

4.1.4 Laminates on which secondary bonds shall be carried out shall have an adequate surface preparation, normally including grinding.

4.1.5 If «peel strips» are used in the bonding surface the required surface treatment may be dispensed with.

4.2 Bonding with rigid adhesives

4.2.1 Adhesive joints for load-bearing parts shall be verified by tests to be agreed on for each individual case, unless comparable experience or results are available.

4.2.2 Only type approved adhesives may be used for bonding. The adhesives may not have any negative effects on the materials to be joined.

4.2.3 If FRP components shall be bonded and a resin adhesive system differing from the laminating system is used, the components shall be totally cured before bonding.

Guidance note:

The various surface pre-treatments for synthetic materials and metals are for example compiled in ISO 17212 and EN 13887.

4.2.4 The surfaces of the materials to be bonded together shall be dry and free of release agents (wax, grease, oil etc.), impurities (dust, rust, etc.) and solvents. Especially when using solvents for cleaning purposes, compatibility with the material and sufficient ventilation time shall be ensured.
4.2.5 Smooth surfaces shall be roughened either mechanically (rough-grinding, sand-blasting etc.) or chemically by etching. Any layers on the surface of the materials to be bonded, that may exert a negative effect on the bonding process (e.g. skin-forming additives in polyester resins or residues of peel ply in the case of FRP, or oxide layers in the case of aluminium) shall be removed.

**Guidance note:**
In many cases, an increase in the strength of the bonded connection can be achieved by the use of specially matched primers. The use of primers is particularly recommended for bonded joints which later in service are relatively heavily stressed by environmental influences.

---end---of---guidance---note---

4.2.6 The adhesive shall be processed in accordance with the manufacturer’s instructions; the proportion of fillers shall not exceed the permitted limit. When mixing the adhesive, its constituents shall be mixed in such a way that they are evenly distributed, care being taken to beat in as little air as possible.

4.2.7 The adhesive shall be applied evenly and as bubble-free as possible to the materials to be joined. If highly thixotropic adhesives are used, it is advisable to apply a thin undercoat of the corresponding pure resin to the surfaces to be joined.

4.2.8 Following application of the adhesive, the materials to be joined shall be brought together without delay and fixed in place.

4.2.9 A loading of the adhesive joint shall not take place before the adhesive has cured sufficiently. For all adhesive joints with thermosetting adhesives, subsequent tempering of the joint is recommended; in the case of cold-curing adhesives, tempering is necessary as a rule.

4.2.10 After curing, the adhesive joint shall be protected by suitable means against penetration by extraneous media (e.g. moisture).

4.3 Bonding with flexible adhesives

4.3.1 The pre-treatment of the joining surfaces and the bonding of structural components shall only be performed by persons with adequate skills and professional knowledge. This professional knowledge shall be documented by means of certificates from the corresponding training courses.

**Guidance note:**
A training course which is regarded as adequate is e. g. the "European adhesive bonder" of the German Welding Society (DVS). Other courses can be recognized, following consultation with the Society.

---end---of---guidance---note---

4.3.2 Adhesive joints for load-bearing parts shall be verified by tests to be agreed on for each individual case, unless comparable experience or results are available.

4.3.3 For the processing of the adhesives, the instructions of the adhesives manufacturer as well as the requirements of the responsible safety authorities and employer’s liability insurance associations shall be observed in addition to these rules. In cases of conflicting requirements, the Society shall be consulted.

4.3.4 During the bonding process, the processing time of the adhesives as specified by the manufacturer shall not be exceeded. If such a time is not specified, qualification tests shall be carried out to determine the permissible pot-life (in the case of thermosetting resin adhesives) or the skin-forming times (in the case of single-component systems) for the relevant environment and batch quantities.

4.3.5 Appliances for joining the components shall be constructed so that the admissible deformations of the components, as specified by the adhesive manufacturer and the designer, are not exceeded during the curing process.
**4.3.6** Fibre-reinforced plastics, thermosetting resins and painted components shall only be bonded when fully cured.

**4.3.7** For the elastic bonding of plastics with each other or with other materials, low-solvent adhesives shall be used.

**4.3.8** A design suitable for bonding shall be used which, as far as possible, avoids peeling moments and forces and for which, under long-term static loading, no creep occurs that could impair the function of the bonded joint.

**4.3.9** If low stresses is required, in the parts in case of the deformation of the parts to be joined the bonding layer shall be thick. The stresses for large deformations shall be kept low through thick bonding layers. Whether thicknesses of less than 3 mm are acceptable shall be clarified in each individual case with the Society. To ensure that the bonding layer is of uniform thickness, flexible spacers (if possible with the same Shore A hardness as the fully cured adhesive) shall be provided.

**4.3.10** The application limits for the adhesive, shall be observed with regard to its resistance to certain temperatures and media, as specified by the manufacturer.

**4.3.11** If necessary, suitable measures shall be taken to protect the edges of the bond against the direct effects of aggressive media (e.g. hydraulic oil), moisture and UV radiation.

**4.3.12** The design shall provide for proper accessibility of the bonding layer for an inspection and for possible repair work.

**4.3.13** The surface pre-treatment shall be arranged so that a surface with defined and reproducible properties is obtained.

**4.3.14** A surface treatment procedure shall be applied, that is suitably effective for the adhesive system and for the parts to be bonded. Furthermore, steps shall be taken to ensure that the properties of the surface do not deteriorate before the bonding process is started.

**4.3.15** If there are coatings on the surface of the materials to be bonded which impair adhesion (e.g. skin-forming agents in UP resins), these layers shall be removed by adopting suitable procedures.

**4.3.16** If bonded joints are used in an environment with corrosive media, the parts to be joined and the joining surfaces shall be treated with a corrosion protection system. The compatibility of the corrosion protection with the adhesive system shall be verified within the procedure test.

**Guidance note:**
In many cases, an increase in the interfacial strength can be achieved through the application of specially matched primers. For each individual object, the use of primers shall be coordinated with the adhesive supplier.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

**4.3.17** If primers or degreasing agents are used, due attention shall be paid to ensuring adequate compatibility with the part to be bonded. The manufacturer’s specifications for the evaporation time shall be observed.

**4.3.18** The suitability of the surface treatment for the chosen adhesive shall be verified by means of a suitable test using the original substrate materials. An example for the assessment of the surface treatment is the peeling test following climatic conditioning.

**Guidance note:**
Various surface pre-treatments for metals and plastics are listed in ISO 17212 and EN 13887.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---
4.3.19 The adhesives intended for processing and the parts to be joined shall be brought into the production shops in good time to ensure proper acclimatization to the processing temperature ($\Delta T \leq 2^\circ C$).

4.3.20 During bonding, a room temperature between 10°C and 30°C and a maximum relative humidity of 70% shall be maintained. During the curing process, only the temperature limits need be observed. If these environmental conditions cannot be provided, the processing conditions shall be coordinated with the adhesive manufacturer and the Society.

4.3.21 The adhesive shall be applied uniformly and free of voids onto the parts to be joined. Care shall be taken to ensure good wetting of the joining surfaces.

**Guidance note:**
If possible, the adhesive shall be applied to the joining surfaces immediately after the surface pre-treatment has been concluded.

---e-n-d---o-f---g-u-i-d-a-n-c-e---n-o-t-e---

4.3.22 The required curing time depends upon the environmental conditions (temperature/humidity, and the ratio of surface area to volume of the adhesive joint, or diffusion path for single-component adhesives). With increasing length of the diffusion path, the curing speed is reduced progressively. The manufacturer’s documentation shall be consulted for reference values.

4.3.23 For the curing of single-component systems, measures shall be taken to ensure a relative humidity of at least 30%, since these adhesives require water to cure properly. If this cannot be ensured, the adhesive shall be wetted after a skin has formed, e.g. by creating a fine mist of water at regular intervals in the vicinity of the adhesive bond using a spray bottle.

4.3.24 Bonded parts shall be loaded by their own weight or an additional load only after the adhesive has undergone sufficient curing.

4.3.25 Details of the working sequences needed for the execution of the adhesive joint shall be described in a work instruction which accompanies each stage of production and is signed by the respective person in charge. Compliance with the required work sequences shall be documented at each stage of production.

4.3.26 Production surveillance of the bonding of the components shall be carried out constantly by the internal quality department. The scope shall be stipulated in an inspection and test plan, and signed by the persons in charge.

4.3.27 The materials used in the production shall be documented. Parameters relevant for the quality (e.g. temperature and humidity) shall also be recorded in the production documentation.

4.3.28 A deferred sample shall be taken from each batch of two-component thermosetting adhesive that is mixed, and this shall be labelled, cured and stored for at least 2 years. If many small batches are removed from one packing unit on a single day, it is permissible to use a dosing report from the second batch and to dispense with the deferred samples. The deferred samples shall be subjected to random testing of their degree of curing, and the results shall be documented. The deferred samples and the dosing report are intended for finding errors in mixing and for detecting inadequacies in the curing cycle.

4.3.29 Parallel to the bonding process, reference samples shall be produced on which the peeling tests shall be performed. The reference samples shall be identical to the parts to be bonded with regard to base material, surface structure, adhesive, and pre-treatment of the bonding surfaces. The reference samples serve to check the compliance with the required surface structure and the pre-treatment quality, as defined by qualification tests. The number of reference samples shall be agreed with the Society for each individual case. Through the use of reference samples, the scope of the structural tests can be reduced.

4.3.30 During and at the end of the bonding process, the parts to be joined, the joining surfaces and the adhesive shall be subjected to a visual inspection. Here special attention shall be paid to good wetting of...
the joining surfaces with the adhesive, and also to voids, discolouration, stress cracking, damage or similar defects.

4.3.31 The quality of the bond shall be determined with non-destructive testing methods, if possible. Ultrasonic testing can be used to determine the presence of adhesive, the thickness of the bonding layer, large voids, and any gap between adhesive and joining surface. By knocking (tapping) on the bonded joint, experienced inspectors can find defects in certain cases. Further testing methods include radiographic inspection and sound emission analysis. However, with non-destructive testing methods it is not possible to detect variations in the adhesion between the adhesive and the joining part.

5 Quality assurance and quality control

5.1 Quality assurance

5.1.1 The production site shall have implemented an efficient system for quality assurance to ensure that the finished product meets the specified requirements. The person or department responsible for the quality assurance shall have clearly established authority and responsibility and be independent of the production departments.

5.1.2 The system shall be formalized through a quality handbook or similar document at least containing the following main objects:
- organisation of all quality related activities
- identification of key personnel and their responsibilities
- procedures for documentation
- qualification of personnel
- manufacturing conditions including recording of temperature and humidity
- receipt and storage of raw materials
- working procedures and instructions
- formulation of resins
- lamination records
- procedures for quality control and inspection or testing
- repair procedures
- defect acceptance criteria.

The quality handbook shall be made available to the surveyor.

5.2 Quality Control

5.2.1 A written quality plan shall be established for the production of each hull and superstructure. The quality plan is subject to approval prior to commencement of the production.

5.2.2 The quality plan shall address at least the following items:
- relevant specifications, rules, statutory requirements etc.
- drawings
- list of raw materials
- procedures for handling of raw materials
- manufacturing procedures and instructions
- procedure for keeping and filing of lamination records
- procedure for keeping and filing of cure logs, temperature and vacuum (for VARTM)
- procedures for quality control and inspection or testing
— inspection points
— witness points by the surveyor
— production testing of laminates, joints and panels in accordance with [5.3]
— procedures for corrective actions when deficiencies are identified.

The quality plan may contain copies of all the necessary documentation or may refer to documents in the quality handbook or other controlled documentation. The relevant drawings may e.g. be identified by a list of drawings.

5.3 Production testing

5.3.1 The purpose of production testing is to verify that a consistent level of quality is maintained throughout production. (Requirements for testing for qualification of material properties to be used in design are given in HSLC Pt.3 Ch.4.

5.3.2 The production site shall specify a production test plan, as part of the quality plan, which as a minimum shall address the following items:
— mechanical strength of sandwich skin laminates, single skin laminates, flanges (caps) of stringers and girders
— bond strength between core and skin laminates in sandwich panels
— mechanical strength of major attachments and joints
— acceptance criteria.

The extent of testing shall not be less than given in Table 1.

Table 1 Extent of testing

<table>
<thead>
<tr>
<th>Area</th>
<th>Testing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hull bottom, sandwich</td>
<td>5 specimen tensile tests of outer skin</td>
</tr>
<tr>
<td>Hull bottom, single skin</td>
<td>5 specimen tensile tests of bottom panel</td>
</tr>
<tr>
<td>Main deck, sandwich</td>
<td>5 specimen tensile tests of outer skin</td>
</tr>
<tr>
<td>Main deck, single skin</td>
<td>5 specimen tensile tests of panel</td>
</tr>
<tr>
<td>1 off main girder or stringer</td>
<td>5 specimen tensile tests of top flange/cap</td>
</tr>
<tr>
<td>Hull bottom, sandwich</td>
<td>5 specimen through-thickness tensile tests</td>
</tr>
</tbody>
</table>

The test methods specified in Sec.2 shall be used. Through-thickness tests shall be carried out according to ASTM C297. The through thickness tensile tests of sandwich may be replaced by peel tests subject to the approval by the Society. For details considered critical with respect to compressive loads compression tests may be required instead of or in addition to the tensile tests. In case more extensive testing is considered necessary by the Society, reliable NDT methods may be considered as an alternative to destructive testing.

5.3.3 The test samples shall be taken from cut-outs in the hull and main deck. All such cut-outs shall be identified by marking and stored until used for testing purposes or until completion of the vessel. If adequate cut-outs are not possible to obtain alternative methods to verify the mechanical strength of the structures shall be agreed upon with the Society.

5.3.4 Material selection, design, fabrication methods and QA/QC procedures may differ significantly between different vessels and yards. A larger or different extent of testing may therefore be required by the Society. The extent of testing may also be made dependent on the degree of utilisation of the particular component or the consequences of a failure of the component.
5.3.5 The test plan is subject to approval prior to commencement of fabrication.

5.3.6 The test results shall be in accordance with the values of mechanical strength used in the design and indicate a level of workmanship in line with good industry standard. The test results shall be submitted to the Society for approval.
SECTION 4 WOODEN MATERIALS

1 General

1.1 Classification according to the field of application

1.1.1 Core materials and including balsa wood for FRP structures are covered in Sec.2.

1.1.2 Only proven boat-building wood shall be used for all timber components exposed to water and weather, i.e. timber with good resistance to water and weather, fungal attack and insect infestation, as well as with good mechanical properties that are also suitable for the particular application. Furthermore, it shall have a low swelling and shrinkage properties.

1.1.3 For components not exposed to water or weather, and not requiring strength, timber of lower durability may be used.

1.2 Quality of timber

1.2.1 The timber used in boat-building shall be long-grained and of the best quality, i.e. be free from sap, shakes, objectionable knots and other defects. Twisted-grown or rough saw cut wood shall not be used.

1.3 Drying

1.3.1 The timber used shall be well seasoned and sufficiently dried, or shall be correctly dried in a suitable drying kiln.

1.3.2 For the purpose of drying, the timber shall be stacked in piles which are as small as possible, so that uniform drying is guaranteed.

1.3.3 In the case of forced drying, the residual moisture content shall not be more than 10%. When processing, this content shall not exceed a maximum of 15% as a result of hygroscopic behavior.

1.3.4 The moisture content shall be determined by establishing the loss of mass of a sample between its state at the time of draw-off and its state after drying, based on constant weight at 103 ± 2°C and the calculation of the weight loss as a percentage of the dry mass. This shall be done in accordance with DIN 52375 or ISO 9425.

2 Types of wood and classifications

2.1 Solid wood

2.1.1 Radially sawn timber shall mainly be used for boat-building. The angle of the annual rings to the lower sawn edge shall not be less than 45°.

2.1.2 The number of different types of timber and their most important properties, such as durability, specific gravity, as well as bending, tensile and compressive strength are shown in Table 1. Since these properties may vary in the case of timber of the same type, or even within the same trunk, no absolute values are indicated in the table, but rather reference values. The timber listed is divided into durability groups from I to V, where:
\[ I \quad = \quad \text{very good} \\
\[ II \quad = \quad \text{good} \\
\[ III \quad = \quad \text{average} \\
\[ IV \quad = \quad \text{moderate} \\
\[ V \quad = \quad \text{poor}. \\
\]

2.1.3 The timber used in boatbuilding shall, if exposed to the weather or used for the primary structural components of a boat, belong to at least durability group III.

2.1.4 In place of the timber listed in Table 1, other types can be used if the durability and the technological values are verified and are equivalent. The manufacturer shall always be responsible for the correct selection of the quality and type of wood.

2.1.5 Since wood has anisotropic material properties, these shall be taken into account during the design of the components. It shall be ensured that the main direction of stress lies in the direction of the greatest strength of wood, and that no impairment of function of the component is caused through the directional moisture coefficient of expansion.

2.1.6 The safety factors used in the strength calculations shall be agreed on in each case with the Society.

**Table 1 Plywood strength groups**

<table>
<thead>
<tr>
<th>Timber type</th>
<th>Botanical name</th>
<th>Density air-dried approx. (g/cm(^3))</th>
<th>Durability</th>
<th>Mean tensile strength of plywood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Longitude (N/(\text{mm}^2))</td>
</tr>
<tr>
<td>Strength group: F1 (for load bearing components)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teak</td>
<td>Tectona grandis</td>
<td>0.64</td>
<td>I</td>
<td>(\geq 40)</td>
</tr>
<tr>
<td>Makoré</td>
<td>Dumoria hekelli</td>
<td>0.62</td>
<td>I</td>
<td>(\geq 40)</td>
</tr>
<tr>
<td>Douka</td>
<td>Dumoria africana</td>
<td>0.62</td>
<td>I</td>
<td>(\geq 40)</td>
</tr>
<tr>
<td>Utile</td>
<td>Entandrophragma utile</td>
<td>0.57</td>
<td>II</td>
<td>(\geq 40)</td>
</tr>
<tr>
<td>Sapele mahogany</td>
<td>Entandrophragma cylindricum</td>
<td>0.59</td>
<td>III</td>
<td>(\geq 40)</td>
</tr>
<tr>
<td>Oak</td>
<td>Quercus sp.</td>
<td>0.63</td>
<td>II</td>
<td>(\geq 40)</td>
</tr>
<tr>
<td>Strength group: F2 1)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bigleaf mahogany</td>
<td>Swietenia macrophylla</td>
<td>0.49</td>
<td>II</td>
<td>(&lt; 40, \text{but} &gt; 30)</td>
</tr>
<tr>
<td>Khaya mahogany</td>
<td>Khaya ivorensis</td>
<td>0.45</td>
<td>II-III</td>
<td>(&lt; 40, \text{but} &gt; 30)</td>
</tr>
<tr>
<td>Okumé</td>
<td>Aucoumea klaineana</td>
<td>0.41</td>
<td>IV-V</td>
<td>(&lt; 40, \text{but} &gt; 30)</td>
</tr>
<tr>
<td>(Gaboon)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1) only for load bearing components
2.2 Plywood

2.2.1 Plywood consists of individual layers which are bonded together. In general, the layers can comprise veneers, wooden slats or small wooden slats. The panels described in the rule requirements as plywood shall consist exclusively of veneer layers.

The plywood panels consist of at least three veneers layers, see Table 2, bonded transversely to each other by means of curable synthetic resin adhesives. The resistance of the adhesives to water and weather shall be demonstrated by long-term and outdoor testing. The number of veneer layers is dependent on the thickness and is defined in [3] and [4].

2.2.2 The plywood panels are divided into two grades Society I and Society II.

Both grades are identical with regard to required strengths, including resistance to adhesives. The only distinction is that the panels of grade Society I are suitable for use in one piece, whilst those of grade Society II may, because of non-permissible defects in the middle and outer layers, only be used separately after removal of the defects.

2.2.3 The dimensions of the plywood panels shall be specified by the customer, if standard dimensions in accordance with DIN EN 313-1 are not used.

The following shall be taken into account: The length of the panels is measured parallel to the grain of the outer layer, and is always specified first. The longitudinal and lateral tolerances are ±5 mm.

The permissible thickness deviation is:

- **up to 3 mm**: ±10%
- **over 3 mm**: ±5%, but maximum ±0.5 mm

2.2.4 The plywood panels shall be bonded without flaws (BFU 100 in accordance with DIN 68705). For this purpose, compliance with all decisive factors such as wood moisture content, pressing power, pressing temperature, pressing duration, glue characteristics, charging etc. shall be observed continually and carefully.

At present, the following synthetically-based adhesives are approved by the Society for plywood production:

- phenolic adhesive (including phenolic adhesive film)
- melamine resin adhesives
- resorcinol resin adhesives.

If a new glue is used, then faultless, error-free handling and bonding shall be demonstrated to the Society as well as absolute resistance to water and boiling.

2.2.5 The safety factors used in the strength calculations shall be agreed on, in each case, with the Society.

3 Boatbuilding plywood

3.1 General

3.1.1 All plywood components exposed to water and weather, or used in primary structural components (such as the deck, shell and bulkheads), shall be produced from boat-building plywood that has been tested and in compliance with [3.10].

3.1.2 Boat-building plywood consists of at least three veneers bonded crosswise together, see Table 2, by means of curable synthetic-resin adhesives. The resistance of these adhesives to water and weather shall be demonstrated by long-term and outdoor testing.
3.1.3 As plywood may also be destroyed in suitable conditions by animal or plant pests, timber shall be used which offers a natural resistance.

3.1.4 Independent of the testing for type approval qualification, the manufacturer is obliged to continually carry out his own shop-based quality control of all working steps, the selection of the wood and its processing during production of the plywood panels.

3.2 Structure

3.2.1 The selection of timber and the structure of the panels (number of veneer layers) shall be appropriate for the field of application. Depending on the application, strong, durable timber - e.g. makoré and the hard, durable mahogany types of strength group F1, see Table 1, with several thin inner layers of veneer shall be selected for load-carrying components subject to high stresses. On the other hand, plywood panels of lighter, less strong and less durable timber of strength group F2 - e.g. khaya mahogany, okumé - with thicker and fewer inner layers of veneer and good surface protection are suitable for linings.

3.2.2 In general, veneers of 1.5 mm thickness are used for the outer layers. However, efforts shall be made to use thicker outer layers because of the later reworking necessary in boat-building. However, their thickness shall not exceed 2.6 mm because of increased danger of shakes in the veneers. In the case of inner layers, veneer layers in plywood panels up to 15 mm thick may not have a thickness in excess of 2.6 mm because of potential defects. For plywood panels thicker than 15 mm, veneer layers thicker than 3.8 mm may not be used.

3.2.3 Only in special cases and with the explicit permission by the Society this restriction can be waived. Such plywood panels are then assigned to the strength group F2 and marked accordingly.

3.2.4 A list of the required minimum number and thickness of the veneer layers are given in Table 2.

### Table 2 Minimum number and thickness of the veneer layers

<table>
<thead>
<tr>
<th>Plywood thickness (mm)</th>
<th>Minimum number of veneer layers</th>
<th>Minimum thickness of the outer layers</th>
<th>Greatest thickness of the inner layers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Up to 6</td>
<td>3</td>
<td>1.5 mm</td>
<td>2.6 mm</td>
</tr>
<tr>
<td>Over 6 to 10</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 10 to 15</td>
<td>7</td>
<td>1.5 mm</td>
<td>2.6 mm</td>
</tr>
<tr>
<td>Over 15 to 20</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 20 to 26</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 26 to 34</td>
<td>11</td>
<td>1.5 mm</td>
<td>3.8 mm</td>
</tr>
<tr>
<td>Over 34 to 40</td>
<td>13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 40 to 48</td>
<td>15</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over 48 to 55</td>
<td>17</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2.5 The veneer layers shall be symmetrical around the middle layer, both with respect to the grain as well as to the thickness of the layers.

3.2.6 The strength of the plywood panel can be increased, or its property adapted to specific requirements, through an increased number of veneer layers, addition of extra glue and increased pressing power, as well as through insertion of fabric layers.
3.2.7 For the production of boat-building plywood panels, only wood which is of the best quality, flawless, healthy, free from sap and spring wood shall be used for the outer and inner layers.

3.3 Veneer joints

3.3.1 The joints shall be sealed perfectly and shall bond the veneers to each other by butt joints. The joints shall be glued on a suitable joint bonding machine.

3.3.2 The strips of veneer of the outer layers shall be put together so that they match with regard to timber and colour.

3.3.3 Sealed joints between all layers are a precondition for boat-building plywood panels.

3.3.4 Paper or plastic adhesive strips shall not be used to secure or repair inner veneer layers.

3.3.5 The joints of the different veneer layers shall be staggered.

3.3.6 Metal clamps used for securing purposes may only be positioned on the edges of the panels. They shall on no account remain on the panels when they are cut to standard dimensions.

3.4 Strength groups

3.4.1 With regard to their suitability for the production of boat-building plywood, the types of timber listed in Table 1 are currently approved. The timber is subdivided into two strength groups. Also shown is the natural durability and weathering resistance of the mentioned types of timber.

3.4.2 The plywood panels may be manufactured from one or several of the approved kinds of timber. If panels comprise different types of timber of both strength groups, then all panels are assigned to the group with the lower strength.

3.4.3 All boat-building plywood panels which are manufactured according to special specifications and conditions of the customer, or deviate from the Society requirements, are assigned to the appropriate group and stamped according to the plywood type.

3.4.4 Other types of wood may only be used for making plywood panels upon agreement with the Society. The manufacturer shall always remain responsible for the correct selection of the quality and type of wood.

3.5 Plywood grades

3.5.1 Boat-building plywood of the two strength groups is subdivided into two grades after inspecting its external and internal quality. In relation to their respective groups, grades I and II are identical with regard to type of wood, strength, production and bonding. They differ insofar that the panels of grade I can be used completely, while the panels of grade II are restricted to partial use because of local manufacturing defects or timber flaws.

3.5.2 The defects of grade II shall be limited to one third of the area of the panel. Two thirds of the panel shall be free of defects and suitable for use. The defects are identified during inspection by marking.

3.5.3 The visible side of the plywood panel shall be manufactured virtually without any defects. The quality, colour and grain shall be combined in such a manner that they match. The hidden surface may have small colour differences or slight blemishes which do not influence the strength of the panel.
3.6 Defects

3.6.1 The following wood and production defects are not permissible in the outer and inner veneer layers:
— any bonding defects
— loose contra-shaving wood; strongly curly-grained, short-fibred wood growth at right angles to the run of the grain; cross-cut timber
— larger, more prominent wood discolouration or mould stains which tend to cause rot and all other defects which could have a noticeable affect on the strength of the panel
— wood discolouration on both sides, or strong glue bleeding on both sides
— loose black (dead) knots, holes, loose joints or blocking cracks in the veneer layers
— overlapping of the veneer layers (folding).

3.6.2 The following may be permitted:
— up to three healthy tight knots of maximum diameter 15 mm for each side of the panel
— up to three knots of maximum diameter 25 mm on each side of the panel which have been perfectly repaired
— up to three cracks of the veneer edge which have been perfectly repaired. The cracks may be up to 1/10 of the panel length and on each side of the panel
— small local edge flaws up to 3 cm length do not have to be considered. Only one of the 4 types of permissible defects shall be present.

3.7 Repairs

3.7.1 Repairs may be carried out on the finished, pressed boatbuilding plywood panels to a limited extent, provided that the quality of the panel is not impaired in any way. The repairs shall be carried out at the appropriate temperature under pressing power with a glue which is resistant to water and weather.

3.7.2 Shakes of up to 1/10 of the panel length and 1 mm width, and small knot holes up to 5 mm diameter may be repaired with wood putty of the same colour.

3.7.3 Wider shakes and defects of up to 1/10 of the panel length shall be bonded so that they are weather resistant. In doing so, care shall be taken when fitting and selecting the strips such that they are from appropriate timber and have the same colour. The repair work shall be carried out under pressure in accordance with DIN 68705 BFU 100.

3.8 Surface treatment

3.8.1 After pressing, the plywood panels shall be subjected to sufficient soaking to ensure that their moisture content again rises to 6 – 12%. The plywood panels may either remain unsanded or be lightly sanded.

3.8.2 The outer layers of the plywood panels cut to their final dimensions shall be at least 1.0 mm (after the pressing and sanding) at the thinnest point. When sanding the panels, special care shall be taken to ensure that this requirement is met.

3.9 Panel dimension

3.9.1 The dimensions of the plywood panels are specified by the customer if standard dimensions are not used, see [2.2.3].
3.10 Testing

3.10.1 The manufacturer is responsible for the inspection. The Society reserves the right to monitor the production of the plywood panels in the manufacturing shop.

Guidance note:
The finished boat-building plywood panels are surveyed and approved at the manufacturing shop by the surveyor, based on the manufacturers inspection. The manufacturer is responsible for the inspection, and the extent of survey by the Society is decided by the surveyor.
The survey of finished plywood panels outside of the manufacturing shop is carried out by the Society only by way of exception and under stricter test conditions.

3.10.2 Inspection of the plywood panels. Particular attention shall be paid to bonding. Panels with faulty gluing shall be examined more closely to determine whether the faults are locally or present over the whole panel. If the latter is true, the entire test batch shall be inspected with special care. If there are several such panels in a test batch, then the entire batch shall be rejected.

If leaky joints or blocking cracks are found at the plywood edges of the inner layers, then these defects shall not be plugged before the survey by the Society. The manufacturer is responsible for compliance with the rules, but the Society shall be given the possibility to finally decide whether these defects can be corrected, or if the panel may be assigned to grade II or shall be rejected. However, this will be based on the manufacturers evaluation.

3.10.3 Grading of the panels shall be in accordance with the differences between grades I and II stipulated in [3.5.1]. The panels are marked with the appropriate grade stamp.

3.10.4 Sampling of test panels:
— for the inspection of boat-building plywood panels, sample panels are taken from test batch intended for inspection and provided with a sample number
— test pieces of approx. 25 cm length and 100 cm width are removed from these sample panels and provided with the sample number of the test panel
— the required samples are prepared from these sample pieces, and again provided with the sample numbers of the test panel
— if only a few panels of a particular plywood type, or very thick and large panels, are submitted for inspection, and if the effort involved in cutting these panels appears to be too great, then samples can also be taken from pieces cut off the edge of these panels. For this purpose, it is necessary, when trimming these panels, to put the edge cuttings aside.

Number of test panels:
— if continuous surveys by the Society in the manufacturing shop show that the production of the boat-building plywood panels appears to be reliable, and if the production is monitored continuously by suitable, automatic facilities or supervision, then it is not necessary to take test panels from each test batch
— it is sufficient to select approximately 2% (by number) of the panels from the current production to be used as samples
— it shall be ensured that the test panels cover all plywood thicknesses and types
— if production problems occur, or if the surveyor has the impression that the production is not always reliable, then the surveyor can insist on the selection a greater number of test panels
— if one or several test panels should exhibit inadequate values during the inspection, then an additional two panels from the same test batch shall be tested. If, once again, the minimum requirements are not satisfied during this inspection, then the complete test batch shall be rejected.

3.10.5 From every test panel (or test strip) to be tested, the following samples shall be taken and prepared:
— two samples for the delamination test in order to determine, in accordance with DIN 53255, the bonding strength of the glue
— eight samples in accordance with DIN 53255 for the adhesive tensile lap-shear test to check the delamination test. Simple tensile lap-shear samples shall be used in accordance with Figure 1
— six samples for the longitudinal strength test and six samples for the transverse strength test to determine the plywood tensile strengths in accordance with DIN 52377
— two kiln-dried samples for the determination of the moisture content of the plywood and the specific weight (apparent density) in accordance with ISO 3130.
3.10.6 Pre-treatment and testing of the samples:

1) glue bonding strength samples

Two delamination samples and eight tensile lap-shear samples are used for testing the bonding strength of the glue.

Before testing, these samples shall be subject to a boiling/drying alternation test and a short-time test BFU 100 in accordance with DIN 68705 and shall satisfy the test conditions of 3) below.

![Diagram of 3-ply longitudinal sample](image1)

![Diagram of 5-ply transverse sample](image2)

**Figure 1 Typical representation of a 3-ply longitudinal and a 5-ply transverse tensile lap-shear sample**

Storage of the samples in boiling water with intermediate drying at 60°C in the following cycle:

- 4 hours boiling
- 16 hours drying
- 4 hours boiling
- 2 hours cooling under water at 20°C.

The two delamination samples shall be subjected to a delamination test after this pre-treatment. The bonding shall offer considerable resistance to the forceful delamination of the veneers by means of a
delamination tool, and the fracture area shall exhibit wood fracture and flawless bonding (cf. fracture diagrams DIN 53255).

The eight tensile lap-shear samples shall be tested in a wet condition in the testing machine and shall satisfy the following minimum values:

— for timber of the strength group F1 at least 1.5 N/mm²
— for timber of the strength group F2 at least 1.2 N/mm²

2) plywood strength test

The six longitudinal tensile-strength samples and the six transverse tensile-strength samples shall undergo acclimatization prior to testing in the testing equipment and their moisture content shall be adjusted to 12 – 15%.

From each of the six samples, three longitudinal and three transverse samples shall be tested in the testing machine and the average strength value determined for these three samples.

The two batches of three remaining samples serve as replacement samples for those samples which exhibit fractures at the clamping device with insufficient values. The fractured samples are then not to be used for evaluation purposes.

The samples shall have the minimum plywood strengths as specified in Table 1. Plywood made from other types of timber shall be included in the strength group with which its properties comply.

If the production and the plywood strength at a manufacturing shop is continually monitored by the Society and if the determination of the plywood strength of individual test batches is considered to be irrelevant, then the inspection and determination of the plywood strengths of these test batches can be waived.

If plywood panels of the timber and strength group F1 do not achieve the required minimum plywood strength values of this group, then these panels can be assigned to the plywood strength group F2 and stamped accordingly.

If plywood panels of the timber and strength group F1 do not achieve the required minimum plywood strength values of this group, then these panels can be assigned to the plywood strength group F2 and stamped accordingly.

3) moisture test

The two kiln-dried samples are used for determining the moisture content of plywood. They shall be examined in accordance with ISO 3130. The moisture content of the plywood shall be 5 – 12% ex works. Measurements of the moisture content of plywood by means of electrical measuring instruments can only be approved if check measurements using the kiln-dried samples have shown approximately identical values.

4) determination of specific weight

For the determination of the specific weight of the plywood panels, the two kiln-dried samples shall be measured and weighed as precisely as possible in dry-air conditions before the kiln-drying.

5) inspection of the plywood scarf jointing

The plywood scarf jointing shall be carried out in accordance with the conditions specified in [4.2] and bonded with glues approved by the Society[2.2] under pressing power and pressing temperature without any flaws. The bonding of the scarf joint shall be checked by bending the panels over a test frame or a roller. If the scarf joints appear to be of doubtful quality, then this bending test shall be performed for both sides of the panels.

6) additional tests

If for any reason the surveyor has any doubts regarding the production and in particular the bonding of the plywood panels and its scarf jointing, then he shall be entitled to subject the test batch to additional tests of his choice, e.g. prising-open tests, knocking-off tests, bending tests, warping tests, soaking tests etc.
3.11 Marking and stamping

3.11.1 All boat-building plywood panels found to be in order shall be provided with the following stamping to identify the plywood type, grade and production:

Stamping by the manufacturer:
— sign or mark of the manufacturing shop
— size and thickness of the panel
— the plywood thickness is given in mm, the length and width of the panel in cm. The first dimension indicates the length of the panel in the longitudinal fibre direction of the outer layers
— timber used for the outer and inner layers (separated by a dash)
— bonding type: "BFU 100"
— boat-building plywood
— strength group
— plywood grade I (or II)
— DNV GL
— testing date
— respective certificate number.

As a rule, the stamping shall be applied on the bottom right of that side of the panel which is of lesser quality (i.e. on the back).

The panels may be stamped neutrally, i.e. without the manufacturer's details, if explicitly so required by the customer.

3.11.2 In the case of long scarf-jointed panels, the Society stamp shall be made on both ends of the panel.

3.11.3 Since inspection is only carried out randomly, the inspector is entitled to reject panels which have already been stamped, if they should prove to be defective.

3.12 Certificates

3.12.1 The Society issues certificates for boat-building plywood panels which have been tested and approved, and these certificates are given to the manufacturer or customer.

3.12.2 The certificate shows, among other things, the plywood types, the number of plywood panels inspected, the stamp and, if requested, the average values of the test results.

3.13 Storage of the plywood panels

3.13.1 Finished plywood panels which are placed in storage shall be kept in closed rooms and stored horizontally.

The plywood panels shall only be placed in horizontal stores that are at least 30 cm above the ground and from the walls, in order to avoid the effects of moisture.

3.13.2 The individual stacks shall be protected against moisture from one side by covering panels.

3.13.3 Non-compliance with these storage requirements can lead to previous tests being declared invalid.
4 Joining of wood materials

4.1 Laminated and multilayered components

4.1.1 In order to reduce variations in the characteristic values of wood and therefore to arrive at reasonable safety factors to be applied in designing structural elements, the wood is homogenized by means of lamination. Laminated components are bonded components consisting of individual layers (at least three) of sawn timber which have the same grain direction.

4.1.2 Multilayered components are bonded components in which the individual layers (at least three) consist of sawn timber and have different grain directions. The thickness of the individual laminates depends on the shape of the components to be laminated. However, the laminate thicknesses shall not, if possible, be less than 5 mm and shall not exceed 25 mm in the case of curved parts. In the case of straight parts, the laminate thickness shall not be more than 40 mm.

4.1.3 Adhesives shall only be used that are resistant to cold and boiling water and that in the bonded joint have the same strength as that of the wood. A precondition for the carrying out of gluing procedures is the availability in the workshops of temperature and humidity controls as well as clamping facilities.

4.1.4 The moisture of the wood shall be 12 – 15% at the time of bonding; but must not exceed 18%. Efforts shall be made to keep the glued joint as thin as possible (0.1 – 0.2 mm).

4.1.5 Since transverse compressive stresses during subsequent swelling of the wood are less damaging than transverse tensile stresses brought about by subsequent volume contraction, it is recommended that the timber be dried to an average moisture content that is the same as, or just below, the average moisture content of the component.

4.1.6 If adhesives on a formaldehyde basis are used (e.g. for boat-building timber), then a pre-drying time for the moist joining surface for 5 – 10 minutes may be necessary to enable low-molecular substances to escape.

4.1.7 Sufficiently long clamping times shall be adhered to, depending on the bonding temperature. In the case of curved or welded parts, the clamping time shall be extended accordingly.

4.2 Scarf jointing

4.2.1 The joint ends shall be precisely joined in order to avoid faulty gluing or other defects.
4.2.2 An illustration of correct joining is given in Figure 2 A, while B depicts incorrect joining; it is especially unsuitable, as faulty gluing occurs frequently because of insufficient pressing power. The method illustrated in C is also wrong and causes a variety of defects. In this case, particularly when sanding plywood panels down until they are smooth, the outer layers are sanded away excessively.

4.2.3 The minimum pressing power shall not fall below 4 kg/cm$^2$.

4.2.4 Glued scarf-jointing of solid wood shall have a chamfer length which is eight times the panel thickness.

4.2.5 For glued scarf-jointing of plywood, the ratio of the plywood thickness to chamfer length shall be as follows:

- for panels up to 10 mm at least 1:10
- for panels over 10 mm at least 1:8.

4.2.6 Further information is given in the VG 81243 Standard (Wood Bonding in Wood Boatbuilding).

5 Wood Protection

5.1 General

5.1.1 All timber (with the exception of the timber of the durability group I, see Table 1), shall be protected by several coats of suitable protective paint, or by means of impregnation with a proven wood preservative, against fungi and insect infestation. Impregnation is the preferred method for interior surfaces of the boat's components which are exposed to water or weather (outer e.g. skin, deck, superstructure) and which have received a coat of paint impervious to vapour pressure.

5.1.2 All plywood parts shall be protected by several coats of paint or varnish. Special attention shall be paid to plywood edges and drill-holes by pre-treating them with recognized and proven edge protection coatings.
SECTION 5 ACRYLIC PLASTIC

1 General

1.1 Scope

1.1.1 In the context of the rules, acrylic plastic for flat or curved windows for view ports shall be made of cast, un laminated polymethyl methacrylate (PMMA).

1.2 Certification

1.2.1 For the manufacture and products of acrylic plastic the following certifications are required:
— approval as acrylic plastic material manufacturer by the Society
— works (W) material certificate
— approval by the Society as manufacturer of acrylic windows
— DNV GL product certificate.

1.3 Acrylic plastic materials

1.3.1 Materials for acrylic windows shall be manufactured in accordance with a recognized standard (e.g. ANSI/ASME PVHO 1, Section 2). The producer is required to certify this before manufacture commences.

1.3.2 Acrylic plastic for windows shall meet the minimum physical requirements stated in Table 1.

1.3.3 For each batch of acrylic plastic processed to windows the manufacturer shall issue a works (W) certificate containing at least the following details:
— number and date of certificate
— manufacturer’s name and address
— designation and application of casting type
— batch number, quantity, shape and size of castings
— marking of castings
— results of tests applied in accordance with Table 1
— stamp and signature.

1.3.4 Where a works (W) certificate of the kind required is not available for the acrylic plastic or where the conditions for recognition of the works (W) certificate are not satisfied, the tests shall be extended in a manner to be agreed with the Society in each individual case.

1.3.5 Each casting shall be provided at one point at least with a marking which identifies the type of casting, the batch number, the date of manufacture and the name of the manufacturer.

1.4 Manufacture of windows

1.4.1 The manufacture of acrylic windows covered by these rules may only take place in specialized workshops which have been approved by the Society for that purpose. Such approval can be granted only to those companies which employ properly trained specialists and which have available the necessary technical facilities enabling them to undertake the expert forming, machining, heat treatment and quality control of acrylic windows. Application for approval shall be made to the Society before the manufacture of windows commences.
1.4.2 The acrylic plastic to be used shall meet the requirements stated below. After machining and any necessary forming operations, each window shall be subjected to heat treatment (tempering) in accordance with the acrylic plastic manufacturer's specification. After tempering no further mechanical polishing may be carried out on the window. Flat disk windows for diving chambers where only the surrounding area is professionally machined need not to undergo a heat treatment after manufacturing.

1.4.3 Window surfaces shall be polished in such a way as to meet the optical clarity requirement stated in Table 1.

1.4.4 For each window or series of windows the window manufacturer shall issue a works (W) certificate specifying all the stages of manufacture such as cutting, sticking, polishing, forming and tempering. In addition the tests carried out, the test results, the marking of the windows and the date of manufacture shall be indicated.

1.4.5 Each window shall be permanently marked with at least the following details:
— design pressure (PR) = nominal diving pressure (NDP) (bar)
— design temperature (°C)
— Society approval stamp
— manufacturer's name or identifying mark
— serial number and year of manufacture
— direction of pressure, if it is not clear.
Wherever possible, the marking shall be engraved in the non-load-bearing portion of the window edge. The use of punches is not allowed.

1.4.6 Acrylic windows shall be presented to the Society for an inspection of manufacture. In addition, each window shall be subjected, in the presence of a surveyor, to a pressure test in accordance with the Society's rules for manned submersibles. At the pressure test the direction of pressure shall be observed. If the windows are subjected to pressure from both sides, this shall be considered for the testing.

### Table 1 Mechanical and optical properties of acrylic plastics

<table>
<thead>
<tr>
<th>Properties</th>
<th>Specified values</th>
<th>Test method</th>
<th>ASTM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultimate tensile strength</td>
<td>≥ 62 N/mm²</td>
<td>DIN 53 455 1) specimen type 3 test velocity II</td>
<td></td>
</tr>
<tr>
<td>Elongation at break (in relation to necking zone)</td>
<td>≥ 2%</td>
<td>DIN 53 457 1) standard climate 23/50</td>
<td></td>
</tr>
<tr>
<td>Modulus of elasticity measured by tensile test</td>
<td>≥ 2760 N/mm²</td>
<td>DIN 53 457 1)</td>
<td></td>
</tr>
<tr>
<td>Compressive yield strength</td>
<td>≥ 103 N/mm²</td>
<td>DIN 53 454 1) standard climate 23/50</td>
<td></td>
</tr>
<tr>
<td>Modulus of elasticity measured by compression test</td>
<td>≥ 2760 N/mm²</td>
<td>Size of test specimen: 25×12.5×12.5 mm</td>
<td></td>
</tr>
<tr>
<td>Compressive deformation</td>
<td>≤ 1%</td>
<td>Constant compressive stress 1) of 27.5 N/mm² for 24 h at 50°C test cube: 12.5 mm edge length</td>
<td></td>
</tr>
<tr>
<td>Non-metallic materials</td>
<td>≤ 5%</td>
<td>UV-spectrophotometer wave length range: 290-370 mm thickness of specimen: 12.5 mm</td>
<td>E308</td>
</tr>
<tr>
<td>------------------------</td>
<td>------</td>
<td>---------------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>Visual clarity</td>
<td>Legibility</td>
<td>A 25 × 25 mm standard type set comprising 7 lines of 16 letters each shall be clearly legible through the acrylic plastic pane at a distance of 500 mm</td>
<td>D702</td>
</tr>
<tr>
<td>Residual monomers methyl methacrylate ethyl acrylate</td>
<td>≤ 1.6%</td>
<td>Gas chromatography</td>
<td></td>
</tr>
</tbody>
</table>

1) the mechanical properties shall be verified on at least 2 specimens
Driven by our purpose of safeguarding life, property and the environment, DNV GL enables organizations to advance the safety and sustainability of their business. We provide classification and technical assurance along with software and independent expert advisory services to the maritime, oil and gas, and energy industries. We also provide certification services to customers across a wide range of industries. Operating in more than 100 countries, our 16,000 professionals are dedicated to helping our customers make the world safer, smarter and greener.